

PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH



UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS



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FEBRUARY, 1925



"OH, TO BE IN ENGLAND NOW THAT APRIL'S THERE, —"

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U. S. DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

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H. S. FAIRBANK, Editor

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IMPRESSIONS OF ENGLISH HIGHWAY PRACTICE

By A. B. FLETCHER, Consulting Highway Engineer, United States Bureau of Public Roads

This article by Mr. Fletcher, the first of a series, to be published in Public Roads, dealing with his observations of English highway practice, was prepared as a paper to be read at the Twenty-second Annual Meeting of the American Road Builders' Association. In it he presents in a pleasant and interesting way some of the more vivid of his impressions gained in a visit to England in the spring of 1924. In subsequent articles he will deal in greater detail with several of the subjects to which he here refers.

DURING THE spring of 1924 I was detailed to study the rural roads of England. With this not unpleasant assignment I was employed during the months of April, May, and June, and although England did not live up to her reputation for fine spring weather—it rained nearly every day—it was possible to get about without particular difficulty even in the remote country districts. One could forgive the rain for the astonishing beauty of the roadsides which it produced.

In addition to meeting the English road officials, the trip included a journey in a Chandler (American-made) automobile from London to Edinburgh, and a little farther north in Scotland, going up through the counties on the east side of the Little Island and returning to London by way of the westside counties, a drive of more than 1,500 miles.

The main north and south roads were rather generally followed, but the large centers of population and the manufacturing cities were avoided for two reasons. I wanted particularly to see the rural roads; and the heavy traffic congesting the narrow, crooked streets of the cities, built when riding in a saddle was more popular than any other sort of transportation, was not tempting to an amateur driver whose forbears for some generations had been taught to drive on the right-hand side of the street.

They say that even Henry Ford had to yield to British conservatism and put the steering wheel on the right-hand side before the English would buy his cars. The Chandler car, originally made with the steering wheel on the left side, had been remodeled so that the wheel, clutch pedal, and brake were moved to the right side. The gear shift, however, was left in the center and had to be worked with the left hand. One soon learned to make the car go, but the idiosyncrasies of the car, together with passing other cars on the wrong side of the road, made such a thing as intuitive driving out of the question. It was not difficult, however, to go as fast as the law permits, for in England as in Massachusetts the legal limit of speed is 20 miles an hour. The law is obeyed equally well in both places, I should say.

The journey, as it was planned, gave an opportunity to inspect a considerable mileage of the two main north and south trunk lines throughout the length of England.

There are many similarities and some differences between the English country roads and the rural roads of the United States. They are perhaps more crooked even than the roads of our older States, and the reason for the poor alignment is apparently the same in both countries. In neither country was there any thought of motor traffic or any other sort of fast traffic when



The narrow, crooked streets of the medieval cities, built when riding in a saddle was popular, are not tempting to an amateur driver

the roads were surfaced. Mostly the roads were improved by putting down hard surfaces within the limits of the then existing rights of way. We seem to be making faster progress in this country in correcting that fault, perhaps not because we are more progressive, as we like to think, but because the urge is greater. The motors have come upon us at a faster rate and in greater numbers, relatively, than in England.

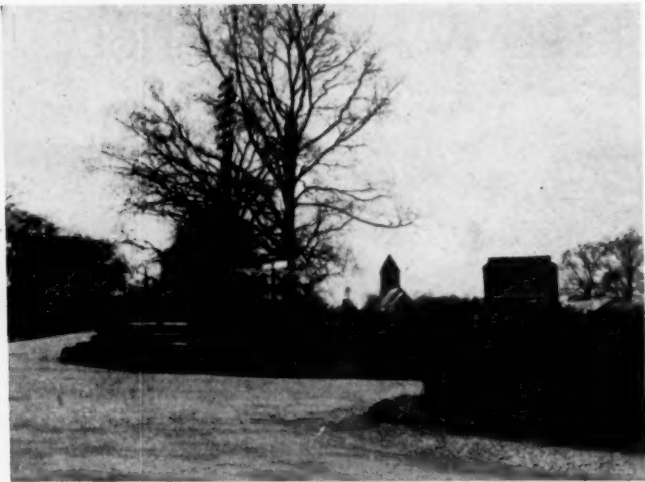
Great Britain still has from 20 to 25 per cent of its highway freight moved by horses, while I suppose that in the United States not more than 10 per cent of the traffic is horse-drawn, and in some of the States the horses are no longer counted in the traffic census.

But when it comes to the matter of the riding quality of the roads we have very much to learn from England. I saw no road on my long auto journey so rough as are most of our rural roads, but it should also be said that I saw hardly any so smooth as the best of the roads in the United States built by the State highway departments with the Federal-aid stimulant.

THE ENGLISH AND AMERICAN ROAD PROBLEMS COMPARED

Our road problem is so much bigger than Great Britain's that the reason for the better average improvement of the English road is apparent. In all England, Wales, and Scotland, there are but 177,000 miles of road, cities and boroughs included, as against our estimated mileage of 2,941,000 outside of the cities and towns. England, Wales, and Scotland have an average of about 242 persons to the mile of road, while in this country there are not more than 35 people to the mile. In Massachusetts, one of our States of dense population, there are about 175 people to the mile.

The English roadside almost invariably is a thing of beauty, and an American has to go to Scotland before he feels at home. For some reason, sparse population and lack of money, perhaps, the Scotch roadsides are nearly or quite as barren and unkempt as



On the whole we mark our roads better than the English. The rectangular object at the right is a dust-covered mirror

most of ours are. The English roads generally have a wide grass border, and there are trees and shrubs everywhere. Sometimes the line of sight is restricted by the roadside growths, but it is plain to understand why even then the shrubs are spared.

The drainage water from the roads disappears quickly from the carriageway and flows off in unseen ditches near the right-of-way lines. The turf at the pavement edge is carefully trimmed and kept so just as in a park. Laborers trimming the edge with spades with a tightly stretched cord for a guide were seen, working as painstakingly as if they were trimming a garden border.

The traffic control at bad road intersections in the country as handled by the agents of the automobile clubs, in cooperation with the police authorities, is wonderfully well done and worthy of much more attention than can be given to it here. In the matter of road signs, however, I was disappointed. I think that on the whole we mark our roads, at least so far as direction signs are concerned, better than it is done in England.

Nearly all of the roads inspected were of some bituminous type, tar-mac, tar macadam, asphalt, tar-painted, etc. In my 1,500-mile journey not more than a mile or two of the road in the open country was recognizable as being of the cement-concrete type, and some of that had been covered with tar or asphalt. I do not imply that no cement-concrete surfaces have been laid on the rural roads, but seemingly most of the work of that type must be in the cities and towns. The English road officials from Sir Henry Mayberry, chief of the road department of the Ministry of Transport, down to the surveyors of the smaller counties seem to be almost a unit in believing that they can not afford to scrap the great mileage of bituminized roads which they have constructed even if it can be proved that the concrete type is more desirable from the viewpoint of maintenance costs, which they seem to disbelieve. They seem to be thoroughly wedded to the bituminous types of construction.

The reason for their preference is clear when one sees the carefully planned grades, long established, with sodded shoulders, drainage ditches and entering driveways, and when one realizes the great expense which

they have incurred in putting in the heavy road foundations. Notwithstanding the large costs of maintaining the bituminous road surfaces, the Englishman is slow to adopt a road type with which he is not familiar, and he is entirely willing that his American cousin shall make what he calls the experiments. He wants proof of the reputed low cost of maintenance of concrete roads, and in his doubting conservatism he will not admit that the relatively few years of life of the American concrete roads have given them any "history" worth talking much about.

THE COST OF MAINTAINING ENGLISH BITUMINOUS ROADS

How large the upkeep charges are for the bituminous roads is shown in some figures published by the ministry showing the annual cost of upkeep on four class 1 roads leading out of London into the Provinces.¹ The total length of the four roads is 321 miles and the report says:

The annual cost of upkeep taken over the whole length of each road ranges from £700 per mile in one case to £980 in another (\$3,360 to \$4,704 per mile).

Assuming the average width of the carriageway of these roads to be 30 feet, and assuming that \$4,000 per mile fairly represents the average annual cost of upkeep, we see that these four roads cost not less than 22½ cents per square yard for maintenance. This annual outlay would appear to be sufficient to renew completely the wearing surface as often as once in five years. The figures, the report says, do not include any capital outlay for the roads in the past.

I have been unable to find a statement showing the mileage or square yardage of concrete roads in Great Britain. The handbook of the British Portland Cement Association states that 281 concrete roads had been built up to June, 1923. Of these, nearly 79 per cent were built after the year 1920. Many of the roads were very short, some less than one-half mile in length, and evidently the total yardage was not sufficiently impressive to be set forth in the handbook.

On the other hand, much of the new arterial road work in the vicinity of London is of the cement-concrete type, some of it 50 feet in width with the slab 8 inches thick, and the work very well executed, some American equipment being employed.

There are so many types of bituminous road in use or offered for use in England that the patentees have had to tax their ingenuity to find names for them all, but from my observation I believe that the great bulk of the pavements are either some sort of penetration macadam, tar-mac, or merely surface-painted.

I was much interested in looking for wavy conditions or corrugations in the surface of the bituminous roads. The county surveyors will tell one that they have waves in their pavements, and they seem to know what one is talking about when one speaks of corrugations, but their waves are not like our waves, for I found very little, practically no, evidence of the corrugations which are so prevalent in our bituminous pavements.

Their methods of spreading the bituminous material are much like ours except that they work more slowly than we do, perhaps more carefully and skillfully, but

¹ Ministry of Transport Report on the administration of the road fund for the year 1922-23.

I am forced to the conclusion that the apparent superiority of the British bituminous roads is due very largely to their thick, heavy foundations and in some measure to the use of curbs to confine the pavements at the sides.

Almost without exception the English road is built with what they call "hard core" as a foundation. Hard core may consist of almost any hard material laid as a foundation for the full width of the carriageway. The stones are large, sometimes as large as 8 inches in longest dimension and often as large as the thickness of the layer will permit. The hard core layer is usually from 8 to 12 inches in thickness. Strong hard slag seems to be a popular material, but when that is too costly and brickbats or stones from walls or buildings are available they are put into the road. The point is, of course, to secure a hard unyielding base which will not hold capillary water. The county surveyors are beginning to wonder if these hard core foundations, strong as from our viewpoint they seem to be, are going to be heavy enough for the future motor traffic. When we consider how few of our rural roads have any foundation at all under the 5 or 6 inches of bituminized stones, do we need to look much further for the cause of the corrugations? Or to explain the apparent superiority of the British roads?

The English seem also to be completely convinced of the need of substantial curbs to prevent the lateral movement of the pavement. All of the new work with which the Ministry of Transport has to do is provided with curbs, and the county surveyors generally are installing curbs in connection with their widening work and extensive repairs.

BASES 12 INCHES THICK

Illustrating the extreme care in the matter of road foundations which some of the county surveyors are taking, C. F. Gettings, of Worcester County, told me when I was looking over some of his work with him that because of the bad subsoil with which he has to deal, he first lays a stratum of "blinder," or cinders, 3 inches thick over the subgrade, followed by a layer of slag 6 inches thick, then a layer of 3-inch slag to a thickness of 3 inches, then 3 inches of tar-mac, and finally a dusting on the top of pulverized slag. Thus he has 12 inches of material in place before he lays the wearing course, which he prefers shall be tar-mac. Tar-mac is crushed slag, heated and mixed with a refined tar at the works where the slag is produced and shipped cold to the highway job.

When conditions permit him to do so, Mr. Gettings employs what we in this country have come to call the stage-construction method. First, after rolling as much as is effective the 6-inch layer of slag, he turns on the traffic to further consolidate it. He does the same with the 3-inch slag layer, sometimes giving it a light tar treatment and allowing the traffic to pass over it for a considerable period, but not after it shows any sign of distress. In this manner he makes sure, before the wearing course is laid, that he has a firm, hard base for it, and that there will probably be no further settlement of his foundation after the pavement is completed.

Some of the best bituminous pavements that I have seen anywhere were built under Mr. Gettings' direction. The traffic over the main Worcester County roads is called heavy. The country is in the Midlands,



English roads have a wide grass border, and there are trees and shrubs everywhere. A pile of hard core material has here been left by the roadside.

one of the regions of great manufacturing activity. The traffic census taken by the ministry in August, 1923, indicates that the roads are in the group of 1,000 to 1,500 tons per 16-hour day. We would not consider that to be a very heavy traffic, but Mr. Gettings thinks a carriageway 22 feet wide and of the thickness before stated is needed for the main roads of the country where the subsoil is bad.

THE COST OF ENGLISH LABOR

In the United States such substantial work would cost much more than the public is accustomed to pay for the rural highways. The English feel the high cost of their road work, too. Common labor in 1924 was receiving the equivalent of 25 cents per hour, a price which the English employer thought was outrageous, yet we at that time were paying more than double the English hourly wage. Living standards and cost of living are different, but I do not believe the disparity is so great as I had been led to believe.

In July, 1924, Portland cement cost in London about \$2.22 per barrel, American basis, and other materials of construction seemed to be not greatly lower in price than in the United States.

The arterial roads near London are of great interest. They are being built in part to supply the general need for more roads, in part to by-pass through traffic so that it will not have to go through the narrow, already congested streets of the metropolis, and in part to provide work for the unemployed.

In England, in 1924, there were more than 1,000,000 persons "on the dole," or supported to a greater or less extent by the Government. Any public work which could be found for these unemployed was welcomed, and for several years the construction of the arterial roads in the Greater London area and the by-pass roads around the cities and towns in the Provinces has provided work for many men. In 1922-23 there was set aside more than \$31,000,000 for the road-fund unemployment program.

In the Greater London area alone, 165 miles of the arterial roads, including the widening and straightening of some roads, are either under construction or planned for, the total estimated cost of the work being in the vicinity of \$60,000,000.

All of this work is being done on a large scale. Rights of way 100 to 120 feet in width are being secured and with much delay and difficulty. When houses are in the way and must be demolished, the public authorities must provide other houses elsewhere to shelter the tenants, so great is the housing shortage.

The carriageways of the most important arterial roads are to be 50 feet wide and curbed. Sidewalks and planting strips are provided for, and iron fences are installed along the right-of-way lines. On the Great West Road all pipes, sewers, water and gas and all electric wires are to be placed in conduits under the sidewalks and planting strips. One section of this road under traffic in 1924 was said to have cost at the rate of £180,000 (\$864,000) per mile.

In the arterial road and by-pass work very low grades are insisted upon, the alignment is as nearly perfect as can be obtained, and no effort seems to be spared in securing the best results in all branches of the work. The pavements, or many of them, are of the cement-concrete-base type laid in most instances with the expectancy of covering them later on with asphalt, but in some cases the concrete is being allowed to take the traffic for the present. The concrete slab, 8 inches thick and reinforced, is said to be costing about 10s. per square yard (\$2.40 approximately).

ENGLISH ROAD ADMINISTRATION

The Ministry of Transport took the place of the road board in 1919, and under Parliament it is the highest road authority of Great Britain. Its organization is somewhat like that of the Bureau of Public Roads. The road department of the ministry is in charge of a chief, Sir Henry Mayberry, with Col. C. H. Bressey under him in the capacity of chief engineer who, in turn, has a corps of divisional engineers located at various places throughout the country in direct charge of the operations.

The revenue which the department has for road purposes, derived almost wholly from the registration fees paid on account of the motor vehicles, amounted in 1924 to about £15,000,000 (\$72,000,000). This is about the same sum that Congress has been appropriating recently for our Federal-aid work, but here the likeness ends. Colonel Bressey told me that the annual revenue which the department received represented, fairly closely, one-third of the total sum spent annually by Great Britain for all highway purposes. Such a sum, approximately \$216,000,000, would not go very far toward paying the annual highway bill of the United States, which in 1922 was estimated to amount to more than \$1,000,000,000.

The ministry has divided the roads into two categories, known as class 1 and class 2, and the present policy is to allot to the counties not more than 50 per cent of the cost of improvements on class 1 roads, and not more than 25 per cent to such work on the class 2 roads. Roads less important than class 2 roads are merely local in character, and they receive no money from the ministry.

In England, Wales, and Scotland, the total mileage of class 1 roads is about 23,000 miles, and the class 2

roads aggregate about 14,000 miles. The total mileage of all roads, including the merely local ones, is given as 177,321 miles, so, roughly speaking, the ministry is concerned with about 21 per cent of the total mileage of the country.

GASOLINE TAX ABANDONED IN 1921

Prior to January 1, 1921, at which time the present road fund was established, there had been in effect a tax on gasoline or "motor spirit," speaking in the language of the country, by means of which most of the grants made by the ministry were financed. After the year 1915 this tax was at the rate of 6 d., about 12 cents per gallon. Beginning with January 1, 1921, the tax was abolished, and in place of the gasoline tax as a revenue producer a tax of £1 (about \$4.80) per horsepower of the motor vehicles was substituted.

This tax is still in effect, and the owner of a Ford car, for example, pays into the public treasury annually very nearly \$100 for the privilege of driving on the British roads. The high registration fee has fostered the manufacture and use of low-powered cars, and special attention has been given to small-cylindrical motors and high piston speeds.

The ministry does not favor a proposed plan to return to a gasoline tax, which the motor interests are pressing for, chiefly, I believe, because the officials dislike to abandon a source of assured income for a plan which they think to be less sure. They say they need at least £15,000,000 per annum for the roads; that the present taxing plan will surely produce that revenue; and that their experience with the collection of the gasoline tax prior to 1921 has not left happy memories. The old relatively high gasoline tax was doubtless evaded in many instances. Sir Henry Mayberry says that while the motors were increasing in numbers from year to year in an astonishing fashion the receipts from the tax remained nearly constant. Much of the gasoline and the kerosene imported into England nominally for heating and manufacturing purposes doubtless found its way into the tanks of the motor cars.

To conclude this somewhat sketchy and superficial summary of some rather large subjects, I believe that in speed of road construction, in the matter of road equipment of all kinds, as concerns motor-vehicle regulation, highway financing, and research and experimental work generally, we do not have much to learn from Great Britain.

In matters of road location we can see there in aggravated form the same sort of mistakes which have been made in this country, particularly in the older States, where we have put down expensive pavements on faulty locations with unnecessarily tortuous alignment, a timid following of the line of least resistance, using rights of way good enough, perhaps, when horses did the work but sadly inadequate for our present-day motorized traffic.

It is doubtful if we can hope to equal the bituminous roads of England until we pay more attention to the foundations. We should either follow somewhat after the English methods or develop some substitute, possibly less costly, which will be as effective.

PERCENTAGE OF WATER FREEZABLE IN SOILS

By A. M. WINTERMYER, United States Bureau of Public Roads

RECENT experiments by the United States Bureau of Public Roads to determine the percentage of water that will freeze at ordinary freezing temperatures in various typical soils have shed new light on probable relations between certain distinguishable characteristics of the soils and the percentage of their contained water that can be frozen.

When a soil "freezes," i. e., when water contained in the soil is frozen, the freezing very seldom involves all the water in the soil. Most soils contain some percentage of water, which may be large or small, depending upon the nature of the soil, that will not freeze at temperatures immediately below the freezing point of water; and in some soils a portion of the contained moisture can not be frozen even at temperatures below -78°C .

If the soil be frozen in a dilatometer, using the method employed in the recent Bureau of Public Roads experiments, which will be later described, the water content can be divided into three volumes determined by the temperature at which they are frozen. The first volume, which will be frozen at 0°C ., is classified as free water; the second, which will freeze at from -4°C . to -78°C ., is classified as capillary or adsorbed water; and the third, classified as combined water, is so intimately associated with the soil that it can not be frozen even at temperatures below -78°C . Different soils differ widely in the percentages of their contained water which fall into these three classes. In some the entire water content can be frozen at 0°C . or slightly below. Clean standard Ottawa sand is such a soil. In other materials, especially those high in soluble salts, with which the contained water combines, the percentage of such salts may be so large that no part of the water may be frozen even at very low temperatures.

As the freezing of water in the soils composing road subgrades, with the accompanying phenomenon of heaving or swelling, is one of the most troublesome of highway problems, it is decidedly worth while to ascertain what properties of the soil affect the percentage of the contained water that may be frozen, for by doing so it is possible that means may be found to alter these properties in such a way as greatly to reduce the troublesome freezing. Yet very little work has been done along this line; indeed, the only published information that has been discovered is that contained in Technical Bulletin No. 36 of the Michigan Agricultural College, by George J. Bouyoucos.

PERCENTAGE OF WATER FROZEN CLOSELY RELATED TO DYE ADSORPTION VALUE OF SOIL

The principal results of the recent experiments by the Bureau of Public Roads are the indication of a fairly close relation between the percentage of water frozen at -1.5°C . and the dye adsorption number of the soil, and the perfecting of the dilatometer method by which the percentage of water frozen may be determined with reasonable accuracy.

It appears as a general rule from these tests that the percentage of water in soil freezable at -1.5°C . increases as the dye adsorption number of the soil decreases. Apparently the adsorption of dye and the water frozen are both controlled by the same properties of the soil, namely, the chemical composition, colloidal content, mineralogical composition, organic-matter content, percentage of soluble and insoluble salts, etc.

The presence of certain constituents or properties which give the soil a high adsorption number causes also the removal of a certain amount of water from the active state, so that the freezing point is lowered very considerably, allowing only a small percentage to be frozen at -1.5°C . In a number of instances in the recent experiments the percentage of soluble salt was so large that no moisture was frozen in the soil even after lowering the temperature to -20°C .

There seems to be a tendency also for the percentage of water frozen to be greater in coarse-grained than in fine-grained soils; but to this tendency there are many exceptions. The mechanical analysis may show a large percentage of coarse material, yet only a small amount of moisture may be frozen. The mechanical analysis shows only the arbitrary size of the soil particles, and not their real condition as, for instance, whether the particles are crystalline or colloidal, etc. A much closer relationship seems to exist between the adsorption number and the moisture frozen; and this is not surprising when we consider that the same factors control both the dye adsorbed and the moisture frozen.

The experiments show also that moisture does not freeze with the same speed in different soils. In some soils the freezing is very rapid; in others very slow. The real freezing point is not at 0°C ., but somewhat lower; in some cases it was found to be below -1.5°C .

Since the dilatometer method, as perfected in these experiments, accurately shows the amount of free or active water in the soil, it would seem advisable to determine this amount of water in the soil in conjunction with the regular soil analysis. It is this water that gives rise to the troubles so often encountered during the freezing season. After the active water has been determined in a particular soil and found to be high in amount, methods may possibly be devised to remove the greater part of this water from the active state by adding some suitable material that will form a combination with it, and lower the freezing point considerably. This would greatly decrease the amount of water frozen and minimize the danger of upheavals.

THE RESULTS OF THE TESTS

In an earlier series of tests, conducted in 1922, the various soil samples were treated with the same amount of water, 5 cubic centimeters in all cases. It was found, however, that this quantity would not moisten the entire sample in all cases. It was decided therefore at the commencement of these tests to try the use of several percentages of water with respect to the volume of the soil, corresponding to the moisture equivalent, and the percentages obtained in the vertical capillarity and water-holding capacity tests,¹ and to run a sufficient number of tests to determine which would be the most favorable percentage for use. On the basis of these trial tests, the percentage of moisture corresponding to the indication of the vertical capillarity test was finally chosen for use in the subsequent tests.

The results of the tests on the various soil samples treated in this way are shown in Table 1, which gives, in addition to the quantity of moisture added to the soil and the percentage frozen, the mechanical analysis and the absorption number of the soil.

¹ For descriptions of these tests, see PUBLIC ROADS, vol. 4, No. 3, July, 1921.

TABLE 1.—Relation between mechanical analyses and adsorption numbers and water frozen in various soils

Soil No.	Total sand	Total fine material	Adsorption number	Water added	Water frozen	Water frozen
	Per cent	Per cent		Cubic centimeters	Cubic centimeters	Per cent
3	38.8	61.2	15.0	6.5	3.45	53.0
4	52.0	48.0	35.0	6.0	3.60	60.0
5	70.4	29.6	7.5	4.0	2.90	72.5
6	41.2	58.8	22.5	6.5	4.70	72.3
7	12.8	87.2	40.0	7.5	4.00	53.4
8	2.5	97.2	30.0	7.5	4.05	54.0
9	1.4	98.6	22.5	7.0	4.50	64.3
10	1.6	98.4	22.5	7.0	4.20	60.0
11	31.2	68.8	8.3	5.5	3.30	60.0
12	37.6	62.4	17.5	7.0	4.50	64.3
13	12.0	88.0	17.5	8.0	6.15	77.0
14	26.8	73.2	55.0	8.0	3.80	47.5
15	26.4	73.6	22.5	7.0	4.30	61.5
16	34.0	66.0	80.0	7.5	4.00	53.4
18	88.1	11.9	11.0	7.0	5.40	77.2
19	28.4	71.6	15.0	5.5	2.45	44.5
20	9.2	90.8	130.0	7.0	1.70	24.3
22	18.0	82.0	90.0	7.5	3.60	48.0
23	47.2	52.8	57.5	8.5	5.35	63.0
24	22.4	77.6	90.0	9.0	5.20	57.8
25	28.4	71.6	150.0	10.5	3.20	30.5
26	15.2	84.8	158.8	9.0	3.60	40.0
27	20.8	79.2	127.5	8.5	3.74	44.0
28	22.0	78.0	45.0	6.5	4.00	61.5
29	66.0	34.0	25.0	6.0	4.24	70.7
31	13.2	86.8	100.0	8.5	3.10	36.5
32	53.6	46.4	42.5	6.0	2.85	47.5
33	3.6	96.4	90.0	9.0	5.30	58.9
36	41.6	58.4	31.3	8.0	3.70	46.3
37	23.2	76.8	55.0	8.0	4.00	50.0
38	90.4	9.6	7.5	5.0	2.55	51.0
40	40.0	60.0	30.0	7.5	3.60	48.0
41	46.8	53.2	16.3	9.0	3.20	35.6
42	8.4	91.6	120.0	11.7	5.30	45.3
43	8.8	91.2	132.5	8.0	2.00	25.0
44	18.0	82.0	140.0	9.0	2.65	33.1
50	17.6	82.4	38.8	9.0	5.00	55.5
51	38.0	62.0	52.5	7.0	4.00	57.2
54	9.9	90.1	52.5	8.0	4.40	55.0
55	14.4	85.6	55.0	7.0	4.00	57.2
56	6.0	94.0	18.8	8.5	5.90	69.4
59	8.8	91.2	40.0	7.5	5.20	69.3
60	12.0	88.0	87.5	8.5	5.40	63.5
67	16.0	84.0	130.0	9.0	4.80	53.4
70	2.6	97.4	55.0	8.0	2.10	26.3
80	31.6	68.4	22.5	6.5	4.05	62.3
92	55.2	44.8	35.0	8.0	4.55	57.0
101	7.2	92.8	87.5	11.0	6.60	60.0
102	4.5	95.5	95.0	8.5	4.70	55.3
103	9.0	91.0	85.0	9.0	6.00	66.7
119	14.4	85.6	20.0	8.0	5.35	66.9
120	1.6	98.4	50.0	10.0	5.75	57.5
138				6.5	2.60	40.0
139				6.0	3.40	56.7
157	35.6	64.4	110.0	8.0	4.20	52.5
158	94.0	6.0	2.5	4.5	3.40	75.6
186	56.4	43.6	35.0	8.0	4.30	53.8
188	78.4	21.6	15.0	5.0	3.75	75.0
200	26.8	73.2	57.5	8.0	5.60	70.0
201	70.8	29.2	15.0	6.0	4.20	70.0
202	70.0	30.0	25.0	3.5	2.35	67.2
290	74.4	25.6	6.3	5.0	4.20	84.0
291	65.6	34.4	7.5	5.5	3.25	59.1
292	30.0	70.0	32.5	13.0	6.20	47.7
293	74.8	25.2	7.5	5.0	4.05	81.0
294	77.6	22.4	30.0	5.0	3.45	69.0
323	30.6	69.4	11.3	9.0	4.00	44.5
324	16.5	83.5	17.5	10.5	5.30	50.5
325	49.4	50.6	11.3	8.0	5.00	62.5
326	29.9	70.1	12.5	8.0	4.10	51.3
327	52.8	47.2	12.5	8.0	4.20	52.5
328	54.1	45.9	10.0	9.0	5.90	65.5
329	24.2	75.8	13.8	9.0	4.90	54.5
410	15.8	84.2	32.5	8.0	0	10
411	3.1	96.9	57.5	10.0	0	10
412	6.4	93.6	25.0	9.0	0	10
413	2.7	97.3	40.0	10.0	0	10
414	7.5	92.5	43.8	9.0	0	10
415	3.3	96.7	50.0	11.0	0	10
416	3.4	96.6	68.8	10.0	0	10
417	15.1	84.9	38.7	10.0	0	10
418	2.9	97.1	67.5	9.0	0	10
419	23.7	76.3	35.0	7.0	0	10
420	38.8	61.2	27.5	8.0	0	10
422	10.6	89.4	31.3	9.0	0	10
423	2.5	97.5	32.5	12.0	0	10
424	5.6	94.4	32.5	10.0	0	10
425	5.3	94.7	58.7	8.0	0	10
426	3.0	97.0	55.0	10.0	0	10
427	3.7	96.3	50.0	9.0	0	10
428	1.4	98.6	67.5	12.0	0	10
430	10.8	89.2	90.0	9.0	0	10
431	7.2	92.8	43.8	10.0	0	10
486	72.0	28.0	10.0	6.5	3.00	46.2
489	59.6	40.4	9.0	6.5	2.90	58.0
492	81.2	18.8	3.0	3.5	2.20	62.9
496	64.6	35.4	9.0	5.5	3.90	70.9
499	71.7	28.3	4.0	5.0	3.60	72.0
500	69.9	30.1	7.0	5.0	2.70	64.0
502	68.1	31.9	9.0	5.5	2.40	43.6
504	71.2	28.8	3.0	5.0	3.70	74.0

TABLE 1.—Relation between mechanical analyses and adsorption numbers and water frozen in various soils—Continued

Soil No.	Total sand	Total fine material	Adsorption number	Water added	Water frozen	Water frozen
	Per cent	Per cent		Cubic centimeters	Cubic centimeters	Per cent
507	53.4	46.6	10.0	5.5	3.20	58.1
508	52.0	48.0	11.0	6.0	3.60	60.0
510	84.2	15.8	2.0	4.0	3.00	75.0
518	88.7	11.3	2.0	4.0	3.20	80.0
523	64.9	35.1	3.0	4.0	2.40	60.0
524	63.2	36.8	6.5	4.5	2.30	51.1
527	63.8	36.2	9.0	6.0	4.50	75.0
530	63.6	36.4	6.0	4.5	2.90	64.5
535	55.2	44.8	11.0	6.0	3.00	50.0
536	53.2	46.8	5.5	4.0	2.30	57.5
538	48.4	51.6	4.0	4.5	2.90	64.5
540	72.5	27.5	2.0	3.5	2.00	57.2
541	63.2	36.8	4.0	4.5	3.40	75.6
542	68.9	31.1	6.0	4.0	2.80	70.0
556	43.0	57.0	10.0	6.0	3.40	56.7
559	43.6	56.4	13.0	6.0	3.10	51.7
562	35.4	64.6	22.0	8.0	4.30	53.8
565	51.9	48.1	16.0	6.5	3.70	56.9
568	44.8	55.2	13.0	6.0	2.40	40.0
569	52.9	47.1	14.0	8.0	4.00	50.0
570	56.2	43.8	12.0	6.0	4.50	75.0
571	74.2	25.8	8.0	4.5	3.90	86.7
572	65.0	35.0	6.0	5.0	3.60	72.0
583	64.6	35.4	27.0	7.0	3.50	50.0
588	71.0	29.0	8.0	4.0	3.20	80.0
591	76.6	23.4	7.0	4.0	2.80	70.0
592	68.2	31.8	16.0	5.0	3.00	60.0
593	64.8	35.2	11.5	4.0	1.60	40.0
595	56.7	43.3	8.0	4.5	3.00	66.7
740	64.6	35.4	7.0	9.0	6.30	70.0
741	75.7	24.3	11.7	9.5	3.80	40.0
742	62.7	37.3	11.7	11.5	3.70	32.2
743	52.8	47.2	19.0	9.0	4.00	44.5
747	61.4	38.6	4.0	8.0	5.60	70.0
749	71.5	28.5	4.5	9.0	6.90	76.7
752	15.9	84.1	23.8	15.0	6.70	44.7
753	49.7	50.3	11.2	4.0	.80	20.0
756	2.9	97.1	55.0	11.0	0	10
757	3.4	96.6	58.7	11.0	0	10
758	6.9	93.1	32.5	10.5	0	10
759	6.6	93.4	40.0	9.0	0	10
760	2.2	97.8	50.0	10.0	0	10
761	3.3	96.7	35.0	10.0	0	10
762	2.1	97.9	40.0	11.5	0	10
763	3.8	96.2	31.3	9.5	0	10
766	10.7	89.3	27.5	8.0	3.60	45.0
772	19.4	80.6	42.5	8.0	4.10	51.3
Quartz sand	100.0					100.0

¹ These soils were all from the Great Salt Desert in Utah. They contain varying percentages of salt, all so high that all water mixed with the samples undoubtedly combined with the salt, so that none of it could be frozen at -1.5°C .

² These soils were from Nevada and were similar to the Utah soils.

Considering the data in Table 1, it will be seen that the amount of water frozen varied from 100 to 0 per cent. The quartz sand, however, was the only soil in which 100 per cent was frozen, and upon grinding this standard Ottawa sand into flour only 70 per cent of the added water was frozen. This seems to indicate that the size of the particles is one of the controlling factors in the amount of water frozen; and, as a general rule, it will be observed that the percentage of water frozen does increase from the fine to the coarse-textured soil. But while there is such a general tendency there is apparently no definite relation between the mechanical analysis and the percentage of water frozen. For example, soils Nos. 5, 201, 290, and 293 all have a high percentage of coarse material and show a high percentage of water frozen. Soil No. 38 is practically all coarse material, yet less of the contained moisture was frozen than in some of the soils which contained only a small amount of coarse material, as, for example, soils Nos. 9, 10, and 59. Soil No. 20 is composed of a large percentage of fine material, and only a small amount of the water was frozen, thus conforming more closely to the general rule than the majority of the soils.

The fact is, of course, that many factors must be considered as influencing the percentage of water that can be frozen at -1.5°C , since soil is more often

heterogeneous than homogeneous. As a rule the condition of the moisture and the temperature at which it will be frozen depend upon the physical, chemical, and mineralogical composition of the soil. Soluble salts, organic matter, and colloidal material present will remove a certain percentage of the moisture from the free state and prevent its freezing.

MECHANICAL ANALYSIS DOES NOT INDICATE FREEZING PERCENTAGE

The mechanical analysis merely shows the size of the soil particles, while the water unfrozen is an index not only of the size of the particles but of other properties as well. Since the adsorption number of the soil indicates in the main the same properties, it might be expected that a relation would exist between the adsorption number and the percentage of water frozen; and, in fact, such a relation is evident in the results of the tests, as will be observed by reference to Table 2, in which certain of the data from Table 1 are arranged in the descending order of the percentage of water frozen.

TABLE 2.—Comparison of percentage of moisture frozen and adsorption numbers of soils

Soil No.	Moisture frozen		Adsorption number		Clay content	
	Each sample	Average	Each sample	Average	Each sample	Average
	Per cent	Per cent			Per cent	Per cent
290	84.0	82.5	6.3	6.9	16.0	15.8
293	81.0		7.5		14.4	
13	77.0		17.5		46.0	
158	75.6		2.5		5.2	
188	75.0	72.9	15.0	20.3	15.9	25.1
5	72.5		7.5		11.6	
6	72.3		22.5		32.0	
29	70.7		25.0		29.3	
200	70.0	65.1	57.5	31.8	40.4	35.9
201	70.0		15.0		20.4	
56	69.4		18.8		28.0	
59	69.3		40.0		34.8	
294	69.0	65.1	30.0	31.8	13.6	35.9
202	67.2		25.0		18.0	
119	66.9		20.0		45.6	
12	64.3		17.5		36.8	
60	63.5	55.8	87.5	60.4	71.8	42.5
23	63.0		57.5		40.8	
80	62.3		22.5		41.8	
15	61.5		22.5		41.6	
11	60.0	45.6	8.3	74.7	22.4	51.4
291	59.1		7.5		19.2	
24	57.8		90.0		52.8	
120	57.5		50.0		76.5	
55	57.2	31.8	55.0	145.0	36.0	58.7
92	57.0		35.0		32.0	
50	55.5		38.8		38.8	
54	55.0		52.5		33.8	
186	53.8	31.8	35.0		35.0	58.7
67	53.4		130.0		55.6	
157	52.5		110.0		45.6	
22	48.0		90.0		56.8	
292	47.7	45.6	32.5	74.7	63.1	51.4
32	47.5		42.5		33.2	
14	47.5		55.0		48.8	
36	46.3		31.3		36.4	
42	45.3	31.8	120.0	145.0	82.0	58.7
19	44.5		15.0		29.6	
27	44.0		127.5		52.0	
26	40.0		158.8		60.4	
44	33.1	31.8	140.0	145.0	71.6	58.7
25	30.5		150.0		45.7	

Even in the data for the individual soil samples in this table there is evident a general relation. Comparing the average values for the several groups, this relation becomes more apparent, for these values show very definitely that as the adsorption number and the clay content of the soil increase the percentage of moisture frozen decreases. Several of the individual values depart from the rule, but no more than one would expect in dealing with a relation in which there are involved so many factors. In this connection the fact that certain classes of dyes are adsorbed more readily by some kinds

of soil than by others must also be taken into consideration. The chemical composition of the soil has a great deal to do with the adsorption. Acid dyes, as a rule, are more strongly adsorbed by basic minerals and soils than are basic dyes, and vice versa. In cases where ammonia exists in the soil as a salt the adsorption may be increased in some instances; in others decreased by the presence of the salt. In these tests methyl violet, a basic dye, was used; and it is quite probable that some of the departures from the general rule in individual samples may be attributed to the basic properties of the dye. Certainly, one would expect that the basic soils would show a relatively lower adsorption number than the acid soils.

TEMPERATURE WHICH SOILS MAY ATTAIN WITHOUT BEING FROZEN

It is known that pure water may be easily cooled to -3° or -4° C. without the appearance of ice if kept quite still while the temperature is reduced. While conducting the freezing experiments it was decided to determine the temperature to which the soils could be lowered and yet remain unfrozen.

The procedure was the same as in the other tests except that the temperature was steadily lowered instead of being maintained at -1.5° C., and the soil was left undisturbed in the freezing mixture. The results obtained showed that all the soils thus treated, about 20 in number, remained unfrozen until the temperature reached -4° C., when they automatically froze. The soil, however, may be kept in the surfused or under-cooled condition an indefinite length of time, and the process of solidification can be started by the slightest vibration or movement. This shows that the soil may very often remain unfrozen even though the temperature be below the freezing point.

EFFECT OF HEATING ON THE AMOUNT OF WATER FROZEN

With a view to determining the effect of heating on the amount of water freezable in the soil samples of a red clay soil were heated to temperatures of 100, 200, 300, 400, 500, and 600° C., respectively, and maintained at these temperatures for one hour, after which water was added in amounts corresponding to the vertical capillarity percentage, and the wet samples were frozen. The heating changed the color of the soil from a light red at 100° C. to a dark brick red at 600° C., and the plastic properties of the soil decreased with increase of temperature.

At 100° and 200° C. the soil was very plastic and froze after considerable agitation at -1.6° and -1.5° C., respectively. The time required for completion of the freezing process after it commenced was in each case 50 minutes.

At 300° C. there was a slight decrease in the plasticity of the soil and the color changed to a slightly darker red. Freezing commenced at -1.5° C. only after considerable agitation, and the time required to complete the process was 60 minutes.

At 400° C. the soil was less plastic and turned to a dark brick red. It froze readily at -1.5° C., requiring 50 minutes.

At 500° C. the plastic qualities were destroyed, the color remaining about the same as that heated to 400° C. The soil froze readily at -1.5° C., and the time required was 1 hour and 30 minutes.

At 600° C. the soil was nonplastic, the color becoming a shade darker. It froze readily at -1.5° C. and required about one and three-quarters hours.

APPARATUS AND METHODS EMPLOYED IN THE TESTS

The apparatus employed in the experiments consisted as shown in Figure 1, of a bath, A, dilatometer, D, and potentiometer, C. The type of dilatometer used had a removable stem with ground joint, as shown in Figure 2. This facilitated the handling and cleaning of the apparatus and removed one of the chief causes of breakage. The dial of the potentiometer used to record the soil temperature was so graduated that the potential difference could be read in

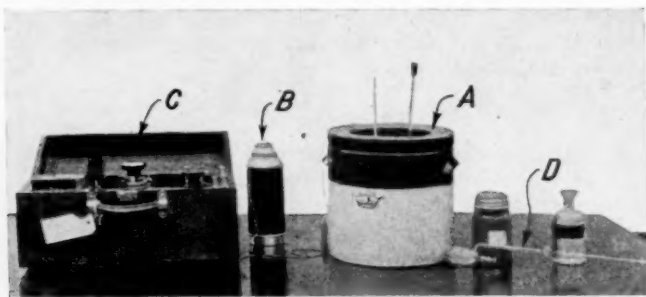


FIG. 1.—Apparatus employed in the dilatometer test

tenths of microvolts. With this arrangement the temperature was controlled to within one-tenth of a degree. For controlling the cold junction temperature an ordinary thermos flask (fig. 1, B) was provided.

The temperature bath consisted of two earthenware jars (fig. 1, A) placed one inside the other. The outer jar was of 3 gallons capacity and the inner of 1 gallon capacity. The space between the two jars was packed tightly with hair, the upper part being made waterproof by a layer of paraffin. The cooling mixture consisted of crushed ice and salt.

In the preliminary tests conducted in 1922 great difficulty was experienced in obtaining concordant results. The variation in some soils was so great that the data obtained were of no value. This variation was found to be due chiefly to the nonuniformity of the sample. Another factor found greatly to aid in obtaining close checks was to let the sample stand overnight and thus insure a more equal distribution of the water added. This method was followed during the final work.

The method of quartering as used is as follows: An aliquot sample of air-dried soil, about 500 grams, was mixed as thoroughly as possible and then quartered. Two opposite quarters were then mixed together thoroughly and again quartered. This procedure was continued until about 25 grams of the original sample remained. This was then thoroughly mixed and the required 25 grams weighed. By following this procedure and by allowing the wet soil to stand overnight very close, and in some cases, perfect checks were obtained. As already stated, the amount of water added in the recorded tests corresponded to the vertical capillarity percentage.

The main procedure was as follows: To 25 grams of air-dry soil the required amount of water was added. The soil and water was thoroughly mixed in the dilatometer. The thermocouple and stopper were then inserted into the neck of the bulb and sealed and allowed to stand overnight. Ligroin or petroleum naphtha was then added through the stem, so that the bulb was just completely filled. The dilatometer was then mildly jarred to set free any air bubbles held by the soil. Finally gentle suction was applied, which quite completely exhausted the air from the soil. The air was excluded from the bulb by filling it and letting

the air escape at the bend. When no more air could be expelled, the stem was filled with ligroin and covered with a paraffined cork cap to prevent volatilization. The ligroin was used to fill the bulb and act as an indicator, because it is not miscible with water.

The bulb of the dilatometer was then placed in the freezing bath and the soil allowed to supercool to -1.5°C . When this temperature was reached, the water in the soil was caused to freeze by gently moving the dilatometer in the freezing mixture until solidification commenced, which was indicated by the rise of the ligroin in the stem. The bulb was allowed to remain in the bath, with frequent shaking, until the rise of the ligroin ceased. The total rise represented the total amount of expansion due to the formation of ice. This water frozen at -1.5°C is regarded as free water.

In order to determine the factor for converting the volume of expansion due to the formation of ice, 5 cubic centimeters of distilled water was added to 25 grams of clean, dry Ottawa sand. Upon freezing this gave an expansion of 0.5 cubic centimeter, showing that 1 cubic centimeter of water will expand 0.1 cubic centimeter upon freezing. This value corresponded to that obtained in the experimental stage of the work.

The time required to complete a determination varied with the class of soil. The speed of solidification at -1.5°C is very low and the greatest amount of time consumed is after crystallization commences. It varies from one-half hour to two hours.

In order to obtain concordant results and eliminate trouble, certain precautions must be observed. The sample should always be thoroughly mixed so that the quantity used will represent a uniform mixture of the whole. As nearly as possible the soil should be allowed to attain the same supercooling temperature. There is little danger of premature solidification at -1.5°C .

The ice bath should be kept dry and constant, at least within 1° below the required temperature. This can be accomplished by siphoning off the water collecting at the bottom of the bath.

Most of the trouble experienced is due to the cork stoppers. These do not always form a tight connection with the neck of the bulb, because of internal unsoundness of the cork or small cracks on the side. It is always best to use sound corks, because the ligroin will be forced through these internal or external openings by the pressure within the bulb and will loosen the paraffin seal. Should this happen, it is better to use a new cork than to try to renew the seal, because it is seldom accomplished. The sides of the corks should also be examined for paraffin. If any is found, it should be removed, because it will be dissolved by the ligroin and allow it to reach the seal and escape.



FIG. 2.—Modified dilatometer

A STUDY OF MOTOR-VEHICLE ACCIDENTS IN MONTANA, OREGON, AND WASHINGTON

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STATISTICS of highway accidents involving motor vehicles which seem to point clearly to congestion of traffic as the principal cause have recently been compiled by the writer from newspaper reports of accidents in the States of Montana, Oregon, and Washington during the greater part of the period from December, 1923, to September, 1924. A classification of the reports, procured from State-wide newspaper clipping services, indicates the relative importance of other causes, such as speed, recklessness, and carelessness

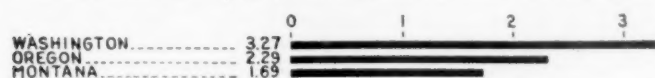


FIG. 1.—Number of accidents per 1,000 motor vehicles

or incompetence of drivers, intoxication, mechanical breakdowns, faulty highway conditions, etc., but these seem to be secondary causes which augment the fundamental condition.

The most striking fact revealed by the compilation is that the accident rate per 1,000 motor vehicles is lowest in Montana, in which the number of motors vehicles registered is lowest, and is higher in the other two States in almost direct proportion to the number of vehicles registered in these States. This indication seems to be directly contrary to the annual statistics of motor-vehicle accidents collected nationally, which show a reduction in the rate of accidents as the registration has increased year by year. The opposing indications of the two compilations are clearly brought out in the following tabulation:

ANNUAL STATISTICS

Year	Number of deaths	Motor-vehicle registration	Fatalities per 1,000 vehicles
1918	7,525	6,146,617	1.23
1919	7,968	7,565,446	1.05
1920	9,103	9,231,941	.99
1921	10,168	10,463,295	.97
1922	11,666	12,238,375	.95
1923	14,412	15,092,177	.96

LOCAL STATISTICS

State	Number of accidents	Motor-vehicle registration	Accidents per 1,000 vehicles
Montana	135	69,100	1.95
Oregon	459	161,739	2.84
Washington	1,012	265,541	3.82
Total	1,606	496,380	3.23

It is possible that the explanation of the difference is that the annual statistics express the salutary results of better traffic regulation, growing familiarity with the motor vehicle, increased caution, and improvements in the design of vehicles and highways; while the State or local statistics, being for the same time and for approximately equal states of advancement with respect to the above factors, express the natural result of differences in traffic density. The probability that this explanation is correct seems to be strengthened by an examination of the particular causes of the accidents

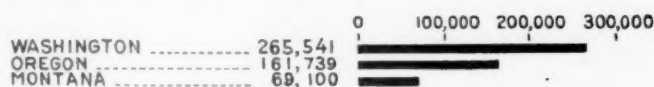


FIG. 2.—Motor-vehicle registration, July 1, 1924

as classified in Table 6, from which it appears that the principal cause contributing to the increase in the accident rate is the element of recklessness and carelessness, a human fault not eradicated by regulation, and not greatly affected by increase of knowledge, but one which becomes more and more potent for disaster as the traffic density increases.

CROWDED ROADS INCREASE ACCIDENT RISK

Considering the summary of the State statistics for the months of December, 1923, and January, April, May, June, July, August, and September, 1924, which are given in Table 1, it is to be remembered that the States represented are among the sparsely settled areas of the West. Yet even in this section it will be observed the accident rate is 3.23 per 1,000 vehicles over an eight-month period. Conservatively estimated for a year the rate becomes 4.5 accidents per 1,000 vehicles. In other words, the average driver in these States has 1 chance in 222 every year to meet with an accident. Assuming the span of driving years over an average lifetime to be 30, the conclusion is that in the Pacific Northwest one driver in every seven is liable to accident during a lifetime of driving. And for the driver who travels the more congested highways the risk is considerably greater.

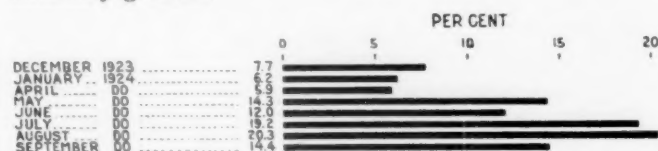


FIG. 3.—Total number of accidents in Montana, Oregon, and Washington, by months

TABLE 1.—General summary of motor-vehicle accident data

	State			Total
	Montana	Oregon	Washington	
Number of accidents	135	459	1,012	1,606
Motor-vehicle registration ¹	69,100	161,739	265,541	496,380
Number of accidents per 1,000 vehicles	1.95	2.84	3.82	3.23
Number of fatalities	33	66	104	193
Ratio of fatalities to accidents (per cent)	24.4	12.2	10.3	12.0
Number of fatalities per 10,000 motor vehicles	4.78	3.46	3.92	3.89
Number of persons injured	168	448	1,035	1,651
Ratio of persons injured to accidents (per cent)	124.4	97.6	102.2	102.8
Number of persons injured per 10,000 motor vehicles	24.3	27.7	39.0	33.2
Number of vehicles damaged	103	386	932	1,421
Ratio of vehicles damaged to accidents (per cent)	76.2	84.1	92.1	88.4
Vehicles damaged per 10,000 motor vehicles	14.9	23.9	35.1	28.6
Mileage of roads	64,732	45,475	45,816	156,023
Motor vehicles per mile of roads	1.1	3.6	5.8	3.2
Population, 1920 census	548,889	783,389	1,356,621	2,688,899
Persons per motor vehicle	7.9	4.8	5.1	5.4

¹ Registration for first six months of 1924 as reported in PUBLIC ROADS, vol. 5, No. 7, September, 1924.

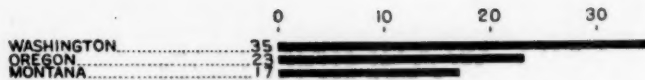


FIG. 4.—Number of cities in three States with population over 2,500

The influence of congestion is suggested by the summarized statistics and by Figures 1 and 2, which show that the frequency of accidents becomes increasingly greater as the number of motor vehicles increases. The suggestion is strengthened by Figure 3, which shows that the greatest number of accidents occurs in the months of July, August, and September, when the roads bear the heaviest traffic, although a comparison of these data with traffic estimates over the entire year seems to indicate that the number of

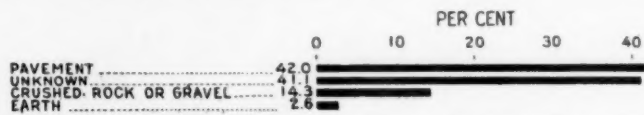


FIG. 5.—Percentage of the total number of accidents in the three States on various types of road

accidents per 1,000 motor cars is greater during the winter months. The previous conclusion may also be inferred from Figure 4, in which it is shown that the number of accidents per 1,000 vehicles increases with the number of cities over 2,500 population. And this inference is again confirmed by the data presented in Figure 5, which show that the greatest number of accidents occurs on paved roads, which, radiating from the more populous centers or serving as the main trans-state traffic lanes, carry the densest traffic.

TIME OF ACCIDENTS

A number of studies have been made to determine whether the accident risk is greater during the day or the night. Table 2 is a summary of the findings over the eight months' period. While these figures are interesting, the study has not been sufficiently detailed to be conclusive.

TABLE 2.—Effect of time of day on causation of accidents

State	Motor-vehicle accidents						Total	
	Daylight		Darkness		Unknown			
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Montana.....	61	45.2	61	45.2	13	9.6	135	100.0
Oregon.....	241	52.5	171	37.3	47	10.2	459	100.0
Washington.....	540	53.4	384	37.9	88	8.7	1,012	100.0
Total.....	842	52.4	616	38.4	148	9.2	1,606	100.0

As shown in Figure 6, the greatest number of accidents occurs during the day, but it is probable that the greatest accident risk is after dark. Figure 7 illustrates the relative amounts of night and day traffic upon the high-

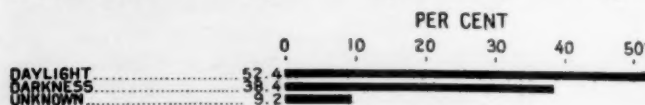


FIG. 6.—Time of accidents in the three States

ways in Oregon during May, 1922, as computed from a traffic census made by the State highway department.¹

¹ This figure is confirmed very closely by the results shown in "A Report of Traffic on State Highways and County Roads in California, 1922," by the U. S. Bureau of Public Roads and California Highway Commission with the cooperation of 24 California counties.

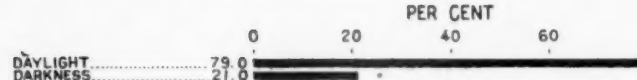


FIG. 7.—Relation of observed day and night traffic in Oregon, May, 1922

Using this information in connection with the present data, Figure 8 has been computed, showing that 2.76 times as many motor vehicles were in accidents after dark as in the daylight. It appears therefore that although the greater number of accidents occurs during

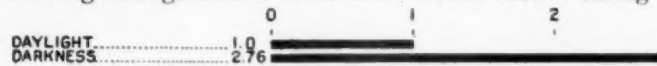


FIG. 8.—Relative number of accidents per motor vehicle in day and night

the day it is probable that the ratio of accidents to the number of motor vehicles on the road is greater at night.

In Figure 3 the summer season is shown as the time of the year during which the greatest number of accidents occurs. It is possible that the greatest number of accidents per 1,000 motor vehicles on the road may occur in the winter months, but no traffic counts are available to confirm this. If 6 per cent of the total annual traffic occurred in December and 15 per cent in July, the accident frequency would be greater during December.² It is noticeable from newspaper accounts that the accidents in the Pacific Coast States become frequent at the

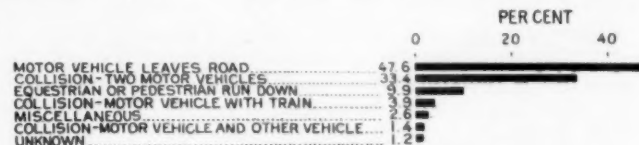


FIG. 9.—Nature of motor-vehicle accidents in the three States, in percentage of total number of accidents

beginning of the rainy season. This may be due to lowered visibility caused by lack of sunlight, to rain or fog in the atmosphere and on the windshield, to use of side curtains, and to skidding, especially on wet or frosty bituminous pavements. A more detailed study will be required to determine during what months the greatest accident risk occurs.

NATURE OF ACCIDENTS

Table 3 and Figure 9 give a summary of the nature of the accidents in the three States over the eight months' period.

TABLE 3.—Nature of accidents

Nature of accident	State						Total	
	Montana		Oregon		Washington			
	Num-ber	Per-cent	Num-ber	Per-cent	Num-ber	Per-cent	Num-ber	Per-cent
Motor vehicle leaves road	73	54.1	222	48.4	470	46.3	765	47.6
Collision of two motor vehicles	31	23.0	164	35.7	341	33.7	536	33.4
Equestrian or pedestrian run down	8	5.9	31	6.8	120	11.9	159	9.9
Collision of motor vehicle and train	15	11.1	23	5.0	25	2.5	63	3.9
Miscellaneous	5	3.7	6	1.3	30	3.0	41	2.6
Collision of motor vehicle and other vehicle	1	.7	8	1.7	14	1.4	23	1.4
Unknown	2	1.5	5	1.1	12	1.2	19	1.2
Total	135	100.0	459	100.0	1,012	100.0	1,606	100.0

² This is a conservative estimate, which is confirmed by the results of the California report and the "Connecticut Highway Transportation Survey," PUBLIC ROADS, vol. 5, No. 1, March, 1924.

The classification "motor vehicle leaves road," means that no collision occurred, although a machine may have swerved from a road to avoid a smash-up or have plunged from the traveled way because of reckless driving, inexperience, intoxication, etc.

LOCATION OF ACCIDENTS

Due to lack of information in the newspaper accounts the location of the accident in more than one-half of the cases is classified as unknown. The balance of the data shown in Table 4 and Figure 10 should be representative, however, of actual conditions.

TABLE 4.—Location of accidents

Location of accident	State						Total	
	Montana		Oregon		Washington			
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Unknown.....	74	54.8	248	54.0	640	63.2	962	59.8
On curve.....	15	11.1	48	10.5	103	10.2	166	10.3
On grade.....	17	12.6	42	9.2	80	7.9	139	8.7
On straightaway.....	7	5.2	47	10.2	77	7.6	131	8.2
Intersection of highways.....	3	2.2	30	6.5	50	4.9	83	5.2
Railroad grade crossing.....	14	10.4	28	6.1	30	3.0	72	4.5
On bridge.....	5	3.7	16	3.5	32	3.2	53	3.3
Total.....	135	100.0	459	100.0	1,012	100.0	1,606	100.0

Contrary to other published data the greatest number of accidents in this section occurs on curves, and the next largest number on grades, which may be on a curve or a straightaway. The number of accidents on the tangents occupies third place. The mountainous character of the country in these three States and the consequent large number of curves may account for the greater number of accidents on the curves. It is conceivable that in the Middle West the greatest number would occur on the straightaways. The grand total curved length of roadway in the State compared with the grand total straightaway length must be an important factor in determining where the greatest number of accidents will occur.

TABLE 6.—Summary of the causes of accidents

	Montana		Oregon		Washington		Total	
	Number	Rate per 1,000 vehicles	Number	Rate per 1,000 vehicles	Number	Rate per 1,000 vehicles	Number	Rate per 1,000 vehicles
Faulty operation by driver:								
Ignorance of traffic rules.....					3	0.01	3	0.01
Incompetence and inexperience.....	2	0.03	5	0.03	8	.03	15	.03
Children drivers.....			1	.01	5	.02	6	.01
Operation by intoxicated persons.....	4	.06	11	.07	26	.10	41	.08
Excessive speed.....	21	.31	34	.21	43	.16	98	.20
Recklessness and carelessness.....	36	.52	197	1.22	478	1.80	711	1.43
Violation of traffic laws.....	3	.04	18	.11	71	.27	92	.19
Miscellaneous.....	3	.04	8	.05	43	.16	54	.11
Total.....	69	1.00	274	1.70	677	2.55	1,020	2.06
Faults of others than driver:								
Child runs across road.....	1	.01	6	.04	24	.09	31	.06
Pedestrian fails to give right of way.....			1	.01	5	.02	6	.01
Miscellaneous.....	19	.28	48	.30	87	.33	154	.31
Total.....	20	.29	55	.34	116	.44	191	.38
Faulty equipment:								
Poor or improperly adjusted brakes.....	3	.04	3	.02	10	.04	16	.03
Glaring headlights.....	3	.04	20	.12	23	.09	46	.09
Driving with only one light.....	1	.01	3	.02	1		5	.01
Driving without lights.....			6	.04	6	.02	12	.02
Baggage extending beyond fenders.....					1		1	
Lack of nonskid appliances.....			1	.01	31	.12	32	.06
Mechanical breakdowns.....	21	.30	24	.15	23	.09	68	.14
Miscellaneous.....	1	.01					1	.01
Total.....	29	.42	57	.35	95	.36	181	.36

KIND OF ROAD SURFACE IN RELATION TO NUMBER OF ACCIDENTS

What bearing does the type of road have upon the accident rate? This is an important question to which engineers are in need of an answer. Table 5 and Figures 5 and 11 show that the greatest number of accidents occurs on pavements, which represent only 1.9 per cent of the rural road mileage of the three States. But this does not mean that pavements are the most dangerous types *per se*, but that the paved roads are more crowded due to their location near populous centers or on main State arteries, and probably to the higher speed made possible by these types of roads. An attempt was made to determine whether the cement concrete or bituminous pavements were the more dangerous, but was abandoned because of lack of sufficient data to support any positive conclusion. The percentage of accidents attributed to skidding was much higher on the bituminous pavements, but the number of accidents per mile of pavement of each type seems to be practically the same. The crowded condition of the road and speed and recklessness seem to be the chief causes of the accidents, and the increased risk due to a slippery pavement seems to be minimized by additional caution on the part of the drivers.

TABLE 5.—Number of accidents in relation to type of road surface

Kind of road surface	State						Total	
	Montana		Oregon		Washington			
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Unknown.....	98	72.6	124	27.0	437	43.2	659	41.1
Pavement.....	8	5.9	267	58.2	400	39.5	675	42.0
Crushed stone or gravel.....	22	16.3	57	12.4	151	14.9	230	14.3
Earth.....	7	5.2	11	2.4	24	2.4	42	2.6
Total.....	135	100.0	459	100.0	1,012	100.0	1,606	100.0

CAUSES OF ACCIDENTS

The causes of accidents are given in summary form in Table 6 and graphically in Figures 12 and 13. The causes are subdivided into faults of persons, equipment, and highway design.

TABLE 6.—Summary of the causes of accidents—Continued

	Montana		Oregon		Washington		Total	
	Number	Rate per 1,000 vehicles	Number	Rate per 1,000 vehicles	Number	Rate per 1,000 vehicles	Number	Rate per 1,000 vehicles
Faulty highway conditions:								
Lack of sight distance					1		1	
Narrow highway	2	0.03	8	0.05	9	0.03	19	0.03
Narrow bridge or culvert			2	.01	1		3	.01
Inadequate, irregular, or improper signs					1		1	
Skiddy surface	8	.12	51	.32	91	.34	150	.30
Lack of guardrail			1	.01			1	
Unnecessary obstruction of view	1	.01	2	.01	5	.02	8	.02
Holes or depressions in highway			2	.01	4	.02	6	.01
Miscellaneous	6	.09	7	.04	12	.05	25	.05
Total	17	.25	73	.45	124	.47	214	.43
SUMMARY								
Faulty operation by driver	69	1.00	274	1.69	677	2.55	1,020	2.06
Faults of others than drivers	20	.29	55	.34	116	.44	191	.38
Faulty equipment	29	.42	57	.35	95	.36	181	.36
Faulty highway conditions	17	.25	73	.45	124	.47	214	.43
Grand total	135	1.95	459	2.84	1,012	3.81	1,606	3.23

TABLE 7.—Detailed analysis of accidents in Montana

	1923	1924								Total	
	December	January	April	May	June	July	August	September		Number	Per cent
Number of accidents	14	5	14	13	19	14	38	18		135	100.0
Results:											
Number of fatalities	3	3	2	1	5	4	12	3		33	24.4
Number of persons injured	17	3	16	17	30	27	42	16		168	124.4
Number of motor vehicles damaged	14	2	11	11	15	11	25	14		103	76.2
Time:											
Daylight	5	3	9	8	9	8	14	5		61	45.2
Darkness	7	2	5	5	9	6	16	11		61	45.2
Unknown	2				1		8	2		13	9.6
Total	14	5	14	13	19	14	38	18		135	100.0
Nature of accident:											
Collision of two motor vehicles	3		3	3	7	3	8	4		31	23.0
Collision of motor vehicle with other vehicle					1					1	.7
Collision of motor vehicle and train	5	1						1		15	11.1
Motor vehicle leaves road	4	1	9		9	9	21	11		73	54.1
Equestrian or pedestrian run down	1	2	1		2		2			8	5.9
Miscellaneous	1	1		1			1	2		5	3.7
Unknown	1					1				2	1.5
Total	14	5	14	13	19	14	38	18		135	100.0
Location:											
Railroad grade crossing	4	1	1			1	6	1		14	10.4
Intersection of highways			1				2			3	2.2
On straightaway	5	1	1							7	5.2
On curve	2	1			3	1	4	3		15	11.1
On grade	1		2	3	2	2	6	1		17	12.6
On bridge			1	2			2			5	3.7
Unknown	2	2	8	5	16	10	18	13		74	54.8
Total	14	5	14	13	19	14	38	18		135	100.0
Kind of road surface:											
Earth				1	1	1	3	1		7	5.2
Macadam, gravel, or crushed rock	1				2	10	6	3		22	16.3
Pavement			2		2	1	1			8	5.9
Unknown	13	5	12	12	14	2	28	12		98	72.6
Total	14	5	14	13	19	14	38	18		135	100.0
CAUSES											
Faulty operation by driver:											
Incompetence and inexperience			1					1		2	1.5
Operation by intoxicated persons			2	2						4	3.0
Excessive speed	1	1	1	5	9	1	2	1		21	15.6
Recklessness and carelessness	10	2	5			1	13	5		36	26.8
Violation of traffic law						2	1			3	2.2
Miscellaneous			1			2				3	2.2
Total	11	3	10	7	9	6	17	6		69	51.3
Faults of others than driver:											
Child runs across road							1			1	.7
Miscellaneous	2	1			1	1	8	6		19	14.1
Total	2	1			1	1	9	6		20	14.8
Faulty equipment:											
Poor or improperly adjusted brakes							3			3	2.2
Glaring headlights	1			1				1		3	2.2
Driving with only one light					1					1	.7
Mechanical breakdowns		1	3	3	4	4	1	5		21	15.6
Miscellaneous					4		1			1	.7
Total	1	1	3	4	5	4	5	6		29	21.4
Faulty highway conditions:											
Narrow highway				1			1			2	1.5
Unnecessary obstruction of view							1			1	.7
Skiddy surface					2	3	3			8	5.9
Miscellaneous			1	1	2		2			6	4.4
Total			1	2	4	3	7			17	12.5
SUMMARY OF CAUSES											
Faulty operation by driver	11	3	10	7	9	6	17	6		69	51.3
Faults of others than driver	2	1			1	1	9	6		20	14.8
Faulty equipment	1	1	3	4	5	4	5	6		29	21.4
Faulty highway conditions			1	2	4	3	7			17	12.5
Grand total	14	5	14	13	19	14	38	18		135	100.0

TABLE 8.—Detailed analysis of accidents in Oregon

	1923	1924							Total	
	December	January	April	May	June	July	August	September	Number	Per cent
Number of accidents.....	41	39	37	65	45	101	73	58	459	100.0
Results:										
Number of fatalities.....	2	3	10	10	6	8	15	2	56	12.2
Number of persons injured.....	40	45	29	61	56	93	70	54	448	97.6
Number of motor vehicles damaged.....	42	44	34	48	36	78	62	42	386	84.1
Time:										
Daylight.....	17	25	24	32	25	48	35	35	241	52.5
Darkness.....	22	13	12	32	16	37	26	13	171	37.3
Unknown.....	2	1	1	1	4	16	12	10	47	10.2
Total.....	41	39	37	65	45	101	73	58	459	100.0
Nature of accident:										
Collision of two motor vehicles.....	17	14	13	25	12	34	34	15	164	35.7
Collision of motor vehicle with other vehicle.....		1	1		2	1	2	1	8	1.7
Collision of motor vehicle and train.....	3	3	3	6	1	2		5	23	5.0
Motor vehicle leaves road.....	15	18	16	33	24	54	31	31	222	48.4
Equestrian or pedestrian run down.....	5	3	2	1	5	7	5	3	31	6.8
Miscellaneous.....					1	2	1	2	6	1.3
Unknown.....	1		2			1		1	5	1.1
Total.....	41	39	37	65	45	101	73	58	459	100.0
Location:										
Railroad grade crossing.....	3	4	5	5	2	3	1	5	28	6.1
Intersection of highways.....	5	2	3	3	3	4	6	4	30	6.5
On straightaway.....	12	7	4	10		3	6	5	47	10.2
On curve.....	5	3		10	6	11	5	8	48	10.5
On grade.....	4	2	2	5	4	9	7	9	42	9.2
On bridge.....		2	4	1	2	4	3		16	3.5
Unknown.....	12	19	19	31	28	67	45	27	248	54.0
Total.....	41	39	37	65	45	101	73	58	459	100.0
Kind of road surface:										
Earth.....				1	1	4	5		11	2.4
Macadam, gravel, or crushed rock.....	9		7	9	6	20	4	2	57	12.4
Pavement.....	25	39	21	41	24	52	35	30	267	58.2
Unknown.....	7		9	14	14	25	29	26	124	27.0
Total.....	41	39	37	65	45	101	73	58	459	100.0
CAUSES										
Faulty operation by driver:										
Incompetence and inexperience.....	3			1			1		5	1.1
Children drivers.....				1					1	.2
Operation by intoxicated persons.....	3		2	2	1	1	1	1	11	2.4
Excessive speed.....	2	2	1	4	7	4	10	4	34	7.4
Recklessness and carelessness.....	21	12	15	27	15	45	34	28	197	43.0
Violation of traffic law.....	3	1		4		8		2	18	3.9
Miscellaneous.....		3	1		2	2			8	1.7
Total.....	32	18	19	39	25	60	46	35	274	59.7
Faults of others than driver:										
Child runs across road.....		2	1			1	1	1	6	1.3
Pedestrian fails to give right of way.....							1		1	.2
Miscellaneous.....	1	1	8	7	5	14	8	4	48	10.5
Total.....	1	3	9	7	5	15	10	5	55	12.1
Faulty equipment:										
Poor or improperly adjusted brakes.....						1	1	1	3	.7
Glaring headlights.....	5	2	1		3	3	2	4	20	4.4
Driving with only one light.....				1		2			3	.7
Driving without lights.....	2	2				1	1		6	1.3
Lack of nonskid appliances.....			1						1	.2
Mechanical breakdowns.....	1			3	4	7	2	7	24	5.2
Total.....	8	4	2	4	7	14	6	12	57	12.5
Faulty highway conditions:										
Narrow highway.....			1		1	5		1	8	1.7
Narrow bridge or culvert.....			1	1					2	.4
Lack of guardrail.....			1						1	.2
Unnecessary obstruction of view.....							1		1	.4
Holes or depressions in highway.....				1				1	2	.4
Skiddy surface.....		14	4	12	4	5	9	3	51	11.1
Miscellaneous.....				1	3	2	1		7	1.5
Total.....		14	7	15	8	12	11	6	73	15.7
SUMMARY OF CAUSES										
Faulty operation by driver.....	32	18	19	39	25	60	46	35	274	59.7
Faults of others than driver.....	1	3	9	7	5	15	10	5	55	12.1
Faulty equipment.....	8	4	2	4	7	14	6	12	57	12.5
Faulty highway conditions.....		14	7	15	8	12	11	6	73	15.7
Grand total.....	41	39	37	65	45	101	73	58	459	100.0

TABLE 9.—Detailed analysis of accidents in Washington

	1923	1924							Total	
	Decem- ber	January	April	May	June	July	August	Septem- ber	Number	Per cent
Number of accidents.....	69	55	44	152	128	194	215	155	1,012	100.0
<i>Results:</i>										
Number of fatalities.....	8	7	12	12	24	11	17	13	104	10.3
Number of persons injured.....	75	36	92	158	196	159	187	132	1,035	102.2
Number of motor vehicles damaged.....	67	57	103	111	146	147	168	133	932	92.1
<i>Time:</i>										
Daylight.....	32	27	28	89	70	106	109	79	540	53.4
Darkness.....	31	23	16	54	47	75	78	60	384	37.9
Unknown.....	6	5		9	11	13	28	16	88	8.7
Total.....	69	55	44	152	128	194	215	155	1,012	100.0
<i>Nature of accident:</i>										
Collision of two motor vehicles.....	25	17	16	45	41	64	73	60	341	33.7
Collision of motor vehicle with other vehicle.....	1			1	3	2	3	4	14	1.4
Collision of motor vehicle and train.....	1	1	1	6	2	5	4	5	25	2.5
Motor vehicle leaves road.....	30	25	17	68	62	99	105	64	470	46.3
Equestrian or pedestrian run down.....	9	11	10	23	15	17	18	17	120	11.9
Miscellaneous.....		1		3	5	7	10	4	30	3.0
Unknown.....	3			6			2	1	12	1.2
Total.....	69	55	44	152	128	194	215	155	1,012	100.0
<i>Location:</i>										
Railroad grade crossing.....	2	1	1	9	2	5	5	5	30	3.0
Intersection of highways.....	5	2	3	8	6	6	9	11	50	4.9
On straightaway.....	12	4	4	8	2	14	17	16	77	7.6
On curve.....	10	2	2	13	12	27	24	13	103	10.2
On grade.....	8	9	3	6	12	15	18	9	80	7.9
On bridge.....	3			5	2	10	10	2	32	3.2
Unknown.....	32	34	31	103	92	117	132	99	640	63.2
Total.....	69	55	44	152	128	194	215	155	1,012	100.0
<i>Kind of road surface:</i>										
Earth.....	1			1	2	7	9	4	24	2.4
Macadam, gravel, or crushed rock.....	4	3	3	24	14	48	33	22	151	14.9
Pavement.....	18	41	20	41	35	86	85	74	400	39.5
Unknown.....	46	11	21	86	77	53	88	55	437	43.2
Total.....	69	55	44	152	128	194	215	155	1,012	100.0
CAUSES										
<i>Faulty operation by driver:</i>										
Ignorance of traffic rules.....					3				3	.3
Incompetence and inexperience.....	2		2		4				8	.8
Children drivers.....								5	5	.5
Operation by intoxicated persons.....	3	1	3						26	2.6
Excessive speed.....	3			8	7	8	6	7	43	4.2
Recklessness and carelessness.....	41	19	16	65	63	97	102	75	478	47.1
Violation of traffic laws.....	10	4	2	12	7	19	9	8	71	7.0
Miscellaneous.....		1	1	1	7	26	6	1	43	4.3
Total.....	59	25	28	86	97	158	128	96	677	66.8
<i>Faults of others than driver:</i>										
Child runs across road.....		2	2	3	2	2	1	12	24	2.4
Pedestrian fails to give right of way.....	1	1	1		2				5	.5
Miscellaneous.....	4	4	6	27	6		24	16	87	8.5
Total.....	5	7	9	30	10	2	25	28	116	11.4
<i>Faulty equipment:</i>										
Poor or improperly adjusted brakes.....				4	2	1	3		10	1.0
Glaring headlights.....	4	4	1	3	2	1	5	3	23	2.3
Driving with only one light.....								1	1	.1
Driving without lights.....		1	1	1					6	.6
Baggage extending beyond fenders.....							1		1	.1
Lack of nonskid appliances.....				1		11	13	6	31	3.1
Mechanical breakdowns.....	1	1	2	14	5				23	2.3
Total.....	5	6	4	23	9	13	25	10	95	9.5
<i>Faulty highway conditions:</i>										
Lack of sight distance.....		1							1	.1
Narrow highway.....				1		5		3	9	.9
Narrow bridge or culvert.....				1					1	.1
Inadequate, irregular, or improper signs.....		1							1	.1
Unnecessary obstruction of view.....			2	1	1			1	5	.5
Holes or depressions in highway.....		3				1			4	.4
Slippery surface.....		11	1	6	10	14	32	17	91	9.0
Miscellaneous.....		1		4	1	1	5		12	1.2
Total.....		17	3	13	12	21	37	21	124	12.3
SUMMARY OF CAUSES										
Faulty operation by driver.....	59	25	28	86	97	158	128	96	677	66.8
Faults of others than driver.....	5	7	9	30	10	2	25	28	116	11.4
Faulty equipment.....	5	6	4	23	9	13	25	10	95	9.5
Faulty highway conditions.....		17	3	13	12	21	37	21	124	12.3
Grand total.....	69	55	44	152	128	194	215	155	1,012	100.0

HIGHWAY SPEED ZONES SUGGESTED

Making the highways safe for the general public should be one of the chief functions of the highway engineer in the development of improved motor transport. The whole problem of regulation has hitherto been too generally regarded as a function of the police authorities, rather than as an engineering and economic problem, the end of which is the provision of safe and adequate highway transportation. Since the appearance of the motor vehicle, public opinion and the consequent attitude of government toward its use have

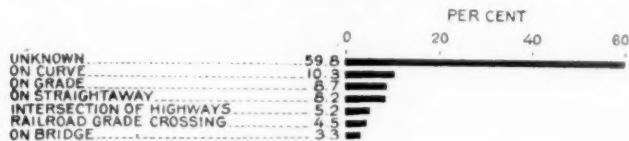


FIG. 10.—Location of accidents in percentage of the total number

passed through two stages. In the first stage, corresponding to the period when motor vehicles were few in number and there was abundant room for them on the roads, they were regarded as a life-menacing luxury, and inflexible and unnecessarily low maximum speed limits were rigidly enforced. In the second stage, which coincides with the increase in motor-vehicle registration to large proportions, the roads have become crowded and at the same time there has been a softening of the rigors of speed regulation, largely the result of growing confidence in the motor vehicle and the overcoming of the fears and jealousies which it inspired in the early days.

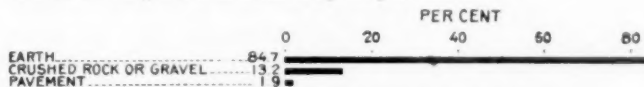


FIG. 11.—Classification of roads, by type, in the three States

It may now be timely to suggest that this liberalizing tendency, desirable as it is in the interest of free transportation, has proceeded "not wisely but too well." Whereas it is certainly essential to impose no more severe restrictions on the operation of vehicles than may be absolutely necessary, it is also important that liberality be kept within the bounds of safety.

The statistics presented in this article clearly indicate that the greater risk exists on crowded highways. It

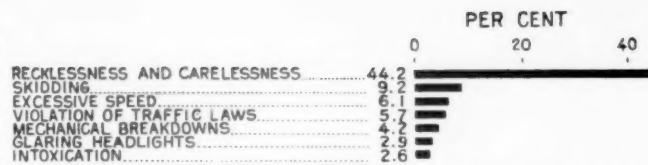


FIG. 12.—Chief causes of accidents in the three States, in percentage of the total number

follows therefore that on such highways there is need of greater care in operation and the adoption of whatever measures may lend themselves to the reduction of the seriousness of unavoidable accidents. While the prevention of recklessness, as already suggested, is difficult of attainment short of the elimination of the reckless driver—and how many are not at times reckless—the reduction of speed on congested roads will go far to prevent the occurrence of the more serious accidents.

Ultimately there will be need undoubtedly for a reduction of congestion by provision of more extensive highway facilities. The part the highway engineer may play in this solution is illustrated by the proposed grade separation and superhighway now planned from Detroit to Pontiac, Mich. The Washington State Highway Department is also preparing to reduce the traffic

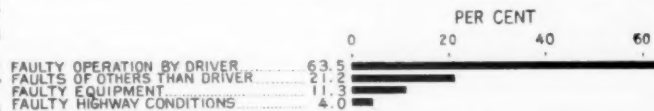


FIG. 13.—Summary of the causes of accidents in the three States, in percentage of the total number

density between Seattle and Tacoma by the construction of two 18-foot parallel pavements separated by a parking space, all built over an entirely new route. Each side of the road will be used by traffic moving in one direction only. But such engineering solutions of the problem will take some time to accomplish, and there is need of immediate relief.

It is believed that the establishment of speed zones, in each of which the maximum speed limit will be determined by the congestion of traffic in the zone, will in some measure provide an immediate remedy. Such a plan is now in effect in Maryland, apparently with favorable results.

CRUSHED-STONE TESTS AND THEIR RELATION TO THE SERVICE OF THE FINISHED PAVEMENT

By A. T. GOLDBECK, Chief Division of Tests, Bureau of Public Roads

THE TREND in the writing of present-day highway specifications is toward definiteness with respect to every item involved. Materials are described in as much detail as our knowledge seems to warrant. It has been found that much contention on the part of the engineer, the contractor, and the materials producer is saved when each one knows definitely what is expected of him. Specifications for materials involve a description of the materials in terms of specific qualities which those materials possess in order to be satisfactory for the particular type of construction contemplated and it is generally the case that where there is much deviation from the specifications, unsatisfactory results are likely to occur.

In general, there are two properties which crushed stone must possess for its successful application to any

particular type of road construction: (1) It must be crushed to the proper size, and (2) it must have physical qualities which make for enduring construction.

Crushed stone was first used to a considerable extent in the building of the macadam type of road in the days of steel-tired traffic. As early as 1878 the first physical test was developed in the French School of Bridges and Roads, primarily as a test of the suitability of stone for waterbound macadam construction. Later the Dorry test for hardness of rock was likewise developed in France, again primarily to determine the suitability of rock for waterbound macadam. In this country other tests were developed by the late Logan Waller Page in the then Office of Public Roads, United States Department of Agriculture. These tests were the Page impact test for determining the toughness of

rock, the cementing value test to determine the binding value of rock dust, and the absorption test. Lately a new test has been developed, but not perfected, the so-called accelerated soundness test for rock.

PHYSICAL TESTS FOR ROCK

The Deval abrasion test.—The Deval abrasion test is made by placing a sample of 50 pieces of uniform-sized stone in a cylinder inclined at an axis. As the cylinder is revolved the pieces of rock and particularly their corners are worn to dust, and the amount of wear is expressed in percentage of the original sample. The French coefficient of wear equals 40 divided by the percentage of wear. Both terms are used and should not be confused.

The Dorry hardness test.—In the Dorry hardness test a cylinder of rock is held against a revolving disk upon which dry crushed quartz is fed, and the amount of wear is determined.

The toughness test.—In the toughness test a 1-inch cylinder of rock is subjected to the impact of a hammer falling from an increasing height on a round-ended plunger resting on the specimen. The toughness of the rock is expressed in terms of the height of fall of the hammer when failure takes place.

Cementing value test.—In the cementing value test the rock is ground to powder and mixed with water in a ball mill, then compressed into a cylinder, which is dried in an oven and finally broken in a special impact machine, whose hammer falls from a constant height of 1 centimeter until the specimen fails. The number of blows required to produce failure indicates the relative cementing value of the rock.

The absorption test.—The absorption test consists simply of determining the amount of water a rock will absorb in a given time.

All of these tests were designed in the days of water-bound macadam, and they have been criticized as being unsuitable in their application to our present-day uses of rock in Portland cement concrete, bituminous macadam, and bituminous concrete pavements subjected to rubber-tired traffic. A discussion of this point will not be amiss at this time. In the days of waterbound macadam and steel tires the rock was subjected to surface abrasion by vehicles, which created a considerable amount of dust, and also to internal wear, due to the grinding of one rock on another. The dust created served to bind the road together, the dust of some rocks possessing this property more than others.

This was the sole reason for the development of the cementing value test. At the present time it has practically no significance for we can no longer depend on the cementing value of the dust to hold the road together. Under rubber-tired traffic very little dust is formed by abrasion and this is rapidly dissipated. There is little excuse then for the cementing value test in present-day specifications for crushed rock.

In bituminous macadam of the penetration type the action of rubber-tired traffic still produces internal wear particularly of the stone not covered with bituminous material. There is still need therefore for some kind of abrasion test such as the Deval test. In the bituminous concrete type of pavement the surface stone is still subjected to forces of high intensity such as impact from high-speed traffic and the action of tire chains and it is likewise our belief that there is the possibility of considerable internal wear when the stone

is too soft. It will be seen therefore that there is still need for tests to determine the strength of the rock. The Deval test and the toughness test both accomplish this purpose.

In concrete pavements the stone is surrounded by Portland cement mortar, which prevents any movement and which offers considerable protection. The stone is subjected only to the abrasive action of traffic and to a slight extent to the disintegrating influence of the weather. It has been found both in service and by means of specially conducted tests that when the stone in a concrete pavement is so soft that it wears faster than the mortar, uneven and rapid wear results, especially where tire chains are used. We need have no fear of abrasive wear from rubber-tired traffic alone. Some of these old-fashioned tests then, such as the cementing value test and Dorry hardness test, no longer have any particular significance when applied to crushed stone as now used in highway construction.

ABRASION AND TOUGHNESS TESTS STILL VALUABLE

On the other hand, since stone under present-day traffic conditions must still possess strength, durability, and resistance to abrasion the tests which measure these properties are still applicable. The Deval abrasion test and the toughness test for rock still have high value, though undoubtedly they might be improved upon. It is for the above reasons that highway specifications for rock still contain clauses which require a specified maximum percentage of wear or a certain minimum toughness. The toughness test has been largely supplanted by the more simple Deval test in many laboratories, for it has been found in general that the Deval test serves every purpose. It is a toughness test and an abrasion test combined. Some specifications further safeguard the quality of the rock through the use of both the toughness and the Deval test.

I have mentioned two other tests, the absorption and the soundness tests. The absorption test measures the amount of water which is absorbed by the rock. Ordinarily rocks which have a high absorption are soft and are not apt to withstand constant repetition of frost action. The accelerated soundness test is a test which is designed to simulate the destructive action of repeated freezing and thawing. As at present performed the rock is immersed in a saturated solution of sodium sulphate for 20 hours, dried for 4 hours in an oven, and this treatment repeated five times. Rocks which are not durable under frost action will disintegrate or crack under this test. Sodium sulphate crystallizes in the pores of the rock, gradually expanding and destroying the structure much after the action of ice. The indications are that the test is too severe. A rock which fails in the test will not necessarily fail in service, but apparently the test does detect rocks which are likely to fail under service.

TEST LIMITS FOR VARIOUS TYPES OF CONSTRUCTION

Problems in economics are involved in the use of materials and for this reason specifications for materials to be used in similar types of construction differ in different States. In some localities it is advisable to use material which in other States is regarded as inferior, for ultimate economy results even though the road does not possess the highest lasting qualities. Crushed stone is now used for the most part in macadam

construction which will later receive a surface treatment of bituminous material, in bituminous macadam, in bituminous concrete, and Portland cement concrete pavements.

Generally where waterbound macadam is built, to be later surface-treated, heavy traffic is not expected. Here good practice would not as a rule allow stone with a percentage of wear of more than 6. Economy may demand, however, that a softer stone be used in certain localities. For bituminous macadam a percentage of wear of more than 6 should not be used; for bituminous concrete, which ordinarily is of a more expensive type laid on a more expensive base than bituminous macadam, the percentage of wear should not be more than 5, and in order to reduce the liability of the stone to fracture, an additional requirement for toughness is used, the value for toughness being set at not less than 6. Instances are known where disintegration of bituminous concrete seems to have resulted from the use of too soft a stone. Many engineers specify a lower percentage of wear for trap or granite than for limestone for a given type of construction. The reason for this is that trap and granite are naturally more resistant than limestone, so that granite, showing a percentage of wear greater than normal for that type, is likely to be partially disintegrated or of otherwise inferior quality even though the actual wear as shown by the tests is the same as the limestone. In connection with waterbound macadam construction certain types of rock, such as quartzite, gneiss, and schist, generally can not be used successfully, due to the difficulty of binding such materials.

In order to study the physical properties of stone desirable for concrete road construction, the Bureau of Public Roads has conducted a rather elaborate test in which 62 different kinds of concrete containing imported aggregates were subjected to the abrasive wear of a special rubber-tired vehicle operated at 20 miles an hour. The vehicle was guided by means of a track so that the wheels ran continuously in the same track. In this way the test was accelerated. The vehicle was first equipped merely with solid tires, and after running it for thousands of trips it was concluded that, so far as rubber-tired traffic alone is concerned, the present wear on concrete roads is not an important factor in limiting the life of the road.

In many sections of the country, however, there are conditions which make for abrasive wear, such as the use of tire chains, and grooves have been worn in concrete pavements due to this cause. The test vehicle was therefore equipped with tire chains and the test repeated and soon the surface wear became very appreciable. This test has been described in detail in PUBLIC ROADS, and the important points brought out were:

That rubber-tired traffic alone produces no appreciable wear on a concrete pavement.

That tires equipped with tire chains cause appreciable wear. This wear is practically independent of the hardness or type of coarse aggregate so long as the coarse aggregate has at least the same resistance to wear as the mortar. When softer aggregates than these are used, the wear of the pavement increases as the stone becomes softer. So far as can be determined the percentage of wear in the Deval abrasion test, which results in equal wear in both stone and mortar, is approximately 7.0.

From the standpoint of abrasive wear alone there seems to have been little choice in this test between crushed stone and gravel. It should be emphasized, however, that abrasive wear is but one of several factors which should influence the choice of an aggregate. The question of

structural strength of the concrete, relative liability to cracking, and subsequent spalling and consequently high maintenance expense must also be considered. It appears from these tests that notwithstanding the fact that the Deval abrasion test was originally designed for macadam road construction it seems to have considerable significance for the specification of rock for concrete road construction.

USE OF SCREENINGS AS FINE AGGREGATE

While discussing the question of physical properties of coarse aggregate for concrete roads, it will be well to consider the use of stone screenings as a fine aggregate in concrete. In general stone screenings are characterized by the presence of an excessively large amount of dust and an excessively large amount of very coarse particles with a corresponding lack of particles of intermediate size when compared with the grading of good concrete sand. One of the tests for the suitability of fine aggregate for use in concrete is the so-called strength-ratio test in which the tensile strength of 1:3 mortar briquets is compared with the tensile strength of Ottawa sand mortar briquets of the same proportions made at the same time. The ordinary assumption is that when these strengths are equal the sand is an excellent concrete material and in general this holds true. When this test is made with stone screenings, it is almost invariably found that the briquets made with the screenings test higher than Ottawa sand briquets, but notwithstanding this fact, it is generally true that concrete made with stone screenings as the fine aggregate has a lower strength than concrete in which sand is used. It is also true that in many cases where stone screenings have been used the concrete has not been resistant to the weather. Particular trouble has been had with limestone screenings, and no doubt this is because the concrete has been lacking in density, due to the poor grading of the screenings. If it were possible for crushed-stone producers to turn out screenings with the same mechanical grading as a good grade of concrete sand there would be no question of its suitability for use.

UNIFORMITY OF CONCRETE

The technical literature of late has placed emphasis on the question of uniformity of concrete. Concrete structures, including highways, are proportioned on the assumption that the concrete has a definite assumed strength. Thousands of concrete cores have been drilled from concrete roads, and the results in many cases show a great lack of uniformity in the concrete, the crushing strength in some cases varying as much as 100 per cent on the same job. It is not sufficient that the concrete shall have an average strength equal to that for which the structure was proportioned when it is so much weaker than that in many spots. It is highly important that everything possible be done to bring about uniformity of strength. Already several of the State highway departments have begun to take measures aiming at more uniform concrete. Iowa is now carefully weighing both sand and stone entering into concrete road construction. Other States although still measuring by volume, are taking into account the fact that the volume of sand may vary 25 per cent due to variable moisture content. Devices are beginning to appear which aim not only to insure more exact measurement of the fine and coarse aggregate, but also of the water used for mixing, which is another of the decided variables which result in lack of uniformity.

There are few engineers who realize the part the coarse aggregate plays in influencing the water content in a concrete mixture and the strength of the resulting concrete. Whenever the gradation of the coarse aggregate changes during the progress of the work, this necessitates changes in the amount of water required to produce a given consistency of concrete.

To illustrate the effect of gradation on consistency, tests were made on 1:2:3 concrete, using both limestone and gravel as the coarse aggregate. The results are indicated in Table 1. It will be observed that changes in the gradation of the coarse aggregated produced a marked effect on the workability. For instance, a certain amount of water produced a slump of 3 inches when a $\frac{1}{4}$ to 2 inch normally graded aggregate was used, whereas exactly the same quantity of water produced a slump of 6 inches when the material between the $\frac{1}{4}$ and 1 inch screens was removed. On the other hand, by maintaining a constant consistency, which of course should be the aim of every mixer operator, fully $\frac{1}{2}$ gallon less of water per bag of cement was required when the stone was graded from 1 to 2 inches than when normally graded from $\frac{1}{4}$ to 2 inches. In a 6-bag batch this would mean a change of 3 gallons in the measured water content and of course a correspondingly large difference in strength.

TABLE 1.—Results of tests of consistency of 1:2:3 concrete, varying the size of aggregate and amount of mixing water

Grading of aggregate	Crushed stone		Gravel	
	Water required per bag of cement for a given consistency	Slump when a constant amount of water is used	Water required per bag of cement for a given consistency	Slump when a constant amount of water is used
Inches	Gallons	Inches	Gallons	Inches
$\frac{1}{4}$ - $\frac{3}{4}$ -----	8.0	1	4.5	2
$\frac{1}{4}$ -1-----	7.7	2	4.4	3
$\frac{1}{4}$ -2-----	7.3	3	4.1	3
$\frac{3}{4}$ -2-----	7.0	4	3.9	6
1-2-----	6.8	6	3.8	7

Producers of stone can aid in the movement for more uniform concrete by maintaining an absolutely uniform product during the progress of the work. This is an ideal which at the present time is not being generally attained. No doubt it is due in part to the present custom of screening aggregates at the producing plant and then more or less inefficiently mixing the various sizes together in a car before shipment. Possibly if more accurate methods were used in combining the screened sizes the desired results would be obtained. One possible solution for obtaining more uniformly graded coarse aggregate is that of shipping the screened sizes separately to the central proportioning plant, stock-piling them there and later combining them in the desired proportions. It is recognized, however, as one of the difficulties in this proposal that ordinarily it is hard to find sufficient space to stock-pile separate sizes, and of course additional time is required to measure the sizes separately at the proportioning plant.

SIZE REQUIREMENTS

In addition to quality requirements for crushed stone, specifications call for grading of the stone in a particular manner for specific types of construction. Unfortunately engineers in different States have different conceptions of what constitutes a proper size of material for the same kind of work, and this of course

leads to needless expense in the producing plant which is called upon to supply materials to several adjacent States. It would be highly economical if a definite standard of sizes could be set up which might be followed by the users of crushed stone. The road materials committee of the American Society for Testing Materials is now at work on the development of such a standard. The standard of sizes proposed by this committee which is designed to meet the requirements of the various types of constructions now used is given in Table 2.

TABLE 2.—Maximum permissible range in mechanical analysis of stone for nominal sizes as proposed by the road materials committee of the American Society for Testing Materials

Designated size	Percentage by weight passing various sizes of laboratory screens									
	$\frac{1}{4}$ inch	$\frac{1}{2}$ inch	$\frac{3}{4}$ inch	1 inch	$1\frac{1}{4}$ inches	$1\frac{1}{2}$ inches	2 inches	$2\frac{1}{2}$ inches	3 inches	$3\frac{1}{2}$ inches
Inches	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
0- $\frac{1}{4}$ ¹	85-100	100	100	100	100	100	100	100	100	100
0- $\frac{1}{2}$ ¹	15-75	95-100	100	100	100	100	100	100	100	100
0- $\frac{3}{4}$ ¹	15-75	95-100	100	100	100	100	100	100	100	100
$\frac{1}{4}$ - $\frac{1}{2}$	0-15	95-100	100	100	100	100	100	100	100	100
$\frac{1}{4}$ - $\frac{3}{4}$	0-15	25-75	95-100	100	100	100	100	100	100	100
$\frac{1}{4}$ -1	0-5	40-75	95-100	100	100	100	100	100	100	100
$\frac{1}{4}$ - $1\frac{1}{4}$	0-5	5-25	40-75	95-100	100	100	100	100	100	100
$\frac{1}{4}$ -2	0-5	5-25	40-75	95-100	100	100	100	100	100	100
$\frac{1}{4}$ - $2\frac{1}{2}$	0-5	10-25	40-75	95-100	100	100	100	100	100	100
$\frac{1}{2}$ -1	0	0-15	25-75	95-100	100	100	100	100	100	100
$\frac{1}{2}$ - $1\frac{1}{4}$	0	0-15	25-75	95-100	100	100	100	100	100	100
$\frac{1}{2}$ -2	0	0-15	25-75	95-100	100	100	100	100	100	100
$\frac{1}{2}$ - $2\frac{1}{2}$	0	0-15	25-75	95-100	100	100	100	100	100	100
$1\frac{1}{4}$ -2	0	0-15	25-75	95-100	100	100	100	100	100	100
$1\frac{1}{4}$ - $2\frac{1}{2}$	0	0-15	25-75	95-100	100	100	100	100	100	100
$2\frac{1}{2}$ -3	0	0-15	25-75	95-100	100	100	100	100	100	100

¹ Designated sizes 0- $\frac{1}{4}$, 0- $\frac{1}{2}$, and 0- $\frac{3}{4}$ when used as screenings in waterbound macadam road construction shall conform to the following additional requirement: Passing 100-mesh sieve, 6 to 12 per cent.

² The lower limit for designated size $2\frac{1}{2}$ -3 inches may be changed to 2 inches when necessary to utilize the product of a crushed producing designated size $\frac{1}{4}$ -2 inches. The upper limit for designated size $2\frac{1}{2}$ -3 inches may be changed to 4 inches in the case of very soft stone or light or porous slag.

It will be observed that the sizes are stated in terms of laboratory screens. This procedure is followed rather than that of stating the size in terms of the size of the commercial revolving screens simply because there are many factors in plant practice which affect the size of the screened stone, whereas the laboratory practice is standardized. It is the individual producer's problem to run his plant in such a manner that the laboratory screen requirements will be met. There is no doubt that the various laboratories will be glad to work with producers to this end for procuring the desired result.

The various sizes of crushed stone and crushed slag recommended by the road materials committee as shown in Table 2 are thought to be adapted for the following uses:

Nominal size	Intended use
Inches	
0- $\frac{1}{4}$	Fine screenings for waterbound road construction.
0- $\frac{1}{2}$	Aggregate for fine-graded bituminous concrete.
0- $\frac{3}{4}$	Coarse screenings for waterbound macadam road construction or aggregate for bituminous concrete.
$\frac{1}{4}$ - $\frac{1}{2}$	Fine dustless screenings for bituminous road construction.
$\frac{1}{4}$ - $\frac{3}{4}$	Coarse dustless screenings for bituminous road construction; coarse aggregate for cement concrete where the maximum size is limited to $\frac{3}{4}$ inch.
$\frac{1}{4}$ -1	Coarse aggregate for coarse-graded bituminous concrete; coarse aggregate for cement concrete where the maximum size is limited to $\frac{1}{4}$ inches.
$\frac{1}{4}$ -2	Coarse aggregate for cement concrete pavements or other concrete structures where the maximum size is limited to 2 inches.
$\frac{1}{4}$ - $2\frac{1}{2}$	Coarse aggregate for cement concrete pavements or other concrete structures where the maximum size is limited to $2\frac{1}{2}$ inches; coarse aggregate for bituminous concrete base.
$\frac{1}{2}$ -1	Commercial $\frac{1}{4}$ -inch stone for bituminous road construction.
$\frac{1}{2}$ - $1\frac{1}{4}$	Commercial 1-inch stone for bituminous road construction; binder stone for sheet asphalt, etc.
$\frac{1}{2}$ -2	Coarse aggregate for bituminous macadam, penetration method, and bituminous macadam base; wearing course for waterbound macadam.
$\frac{1}{2}$ - $2\frac{1}{2}$	Coarse aggregate for bituminous macadam base or base course for waterbound macadam.

REINFORCED CONCRETE PAVEMENT SURVEY

HIGHWAY RESEARCH BOARD REPORTS PROGRESS OF ITS STUDY

By C. A. HOGENTOGLER, Highway Research Board, National Research Council

THE STATUS of the survey for determining the economic value of steel reinforcement in concrete pavements carried on by the highway research board of the National Research Council is such that the procurement of very definite information on this much-discussed question seems assured. As in every other research, it was necessary to have specimens from which were eliminated all variables except those whose effects were to be studied. Instead of being especially constructed, as is ordinarily the case, in this instance they had to be selected from the vast mileage of plain and reinforced concrete roads which has been constructed up to the present time. Since the difficulties attendant upon the attempt to compare a road of one type with another of a different type were keenly appreciated, every effort was made to procure for study only such roads as contained both plain and reinforced sections. The seeking out of such specimens has taken considerable time, since, unfortunately for the purpose, roads are generally either entirely plain or entirely reinforced.

It is now felt that the time and efforts spent in the selection of the desired roads have been amply rewarded, since they have been found in sufficient number to warrant conclusive results. In addition to such experimental service roads as the DeKalb, Ill., and the Sacramento-Riverbank, Calif., surfaces, constructed in 1912; the Du Pont highway in Delaware, constructed in 1915; the Milwaukee County, Wis., and the Los Alamos-Gaviota, Calif., roads, constructed in 1917; and the Columbia Pike, Va., constructed in 1921, there have been located 188 highways whose surfaces contain both plain and reinforced concrete sections which were built at the same time, by the same contractor, under the same supervision, and from

the same materials and have been subjected to the same traffic and climatic conditions. Thus in these roads all undesirable variables are eliminated except those of subgrade and strength of concrete, which are common to all highway experiments. These highways are distributed through 30 States, ranging from Connecticut to California and from Minnesota to Texas, with one in Ontario, Canada. In three counties of New York State alone, representing both good and poor subgrade subjected to extreme frost action, there are 304 sections containing reinforcement, of lengths varying from 100 to 1,000 feet, with a total length of over 200,000 lineal feet, each section being part of a concrete road and having plain sections on each side. Contrasted with this soil condition is one found in Mississippi, where, although frost is lacking, the soil has an extremely high volumetric change. In this location an experimental road 1 mile long, half of which was reinforced, was constructed in 1915.

In addition to differences in subgrade conditions these roads represent age, mix, traffic, and cross-section variations. In the reinforcement are included different weights of mesh and various designs using bars.

The final road inspections are now in progress, and will probably continue throughout the summer, after which the data will be analyzed and a report of the findings submitted. Analyses of subgrade samples taken in connection with the investigation are being made by the United States Bureau of Public Roads. The University of Maryland is cooperating in the examination of cores for determination of the effect of time and cracks on reinforcement; and various State highway departments have offered cooperation in the road inspections and core-drill work for checking location of steel and thickness of slab.

UNITED STATES DEPARTMENT OF AGRICULTURE,
BUREAU OF PUBLIC ROADS
STATUS OF FEDERAL AID HIGHWAY CONSTRUCTION

AS OF

JANUARY 31, 1925

FISCAL YEAR 1925

STATES	FISCAL YEARS 1917-1924				PROJECTS COMPLETED SINCE JUNE 30, 1924				*PROJECTS UNDER CONSTRUCTION				PROJECTS APPROVED FOR CONSTRUCTION				BALANCE OF FEDERAL AID FUND AVAILABLE FOR NEW PROJECTS	STATES
	PROJECTS COMPLETED PRIOR TO JULY 1, 1924				TOTAL COST				ESTIMATED COST				ESTIMATED COST					
	TOTAL COST	FEDERAL AID	MILES		TOTAL COST	FEDERAL AID	MILES		ESTIMATED COST	FEDERAL AID	MILES		ESTIMATED COST	FEDERAL AID	MILES			
Alabama	\$ 4,598,781.43	\$ 1,185,437.54	464.1		\$ 844,187.95	\$ 418,827.78	97.1		\$ 15,357,875.48	\$ 7,448,337.90	837.9		\$ 79,416.15	\$ 39,708.07	0.6		\$ 1,160,491.73	Alabama
Arizona	8,339,355.41	4,297,631.98	527.0		713,175.97	406,825.70	37.5		1,992,346.05	1,208,209.81	169.2		666,410.72	407,643.86	51.6		1,738,030.05	Arizona
Arkansas	11,094,751.31	4,424,345.63	244.4		1,537,569.79	868,353.74	69.1		8,940,986.35	2,895,688.48	373.4		437,270.36	186,840.60	40.8		887,138.56	Arkansas
California	12,999,075.03	5,647,148.17	533.7		6,434,044.02	2,908,132.66	218.8		11,361,648.66	5,714,688.44	321.1		14,898.29	8,785.99	0.1		2,816,645.92	California
Colorado	8,108,070.31	4,029,898.97	502.6		1,114,291.39	570,941.17	53.0		5,336,346.42	2,887,930.04	212.6		540,680.68	213,639.34	14.1		1,807,472.48	Colorado
Connecticut	3,062,872.02	1,269,550.60	73.6		199,024.56	98,423.00	4.9		3,852,054.48	1,045,804.04	54.1						987,409.26	Connecticut
Delaware	3,046,832.22	1,007,714.83	72.5		462,969.09	197,825.82	13.8		1,316,995.48	904,231.10	33.1						29,732.25	Delaware
Florida	3,981,134.07	1,461,470.92	49.8		1,015,010.74	681,331.64	25.4		8,673,890.35	4,183,670.44	246.8						956,571.00	Florida
Georgia	17,167,373.32	7,855,805.20	1,214.2		912,405.15	519,925.76	97.2		2,000,849.49	1,258,594.93	141.1		533,314.64	169,293.34	37.2		54,871.48	Georgia
Idaho	9,181,697.32	4,092,395.52	506.6		4,724,821.20	2,320,686.23	152.4		12,467,882.53	6,188,330.64	468.8		463,729.61	317,767.62	33.8		519,089.17	Idaho
Illinois	26,964,706.06	12,279,546.33	804.7		3,879,536.08	1,569,281.54	112.8		13,919,720.06	6,818,186.90	448.1						2,869,400.58	Illinois
Indiana	7,577,444.16	3,655,540.37	225.7		912,405.15	519,925.76	97.2		2,000,849.49	1,258,594.93	141.1		463,729.61	317,767.62	33.8		519,089.17	Indiana
Iowa	23,195,776.19	9,237,031.66	1,682.9		2,531,765.76	1,237,507.41	202.3		6,787,941.24	3,097,049.47	461.3		2,219,084.80	831,300.00	81.8		933,248.06	Iowa
Kansas	17,084,136.48	6,043,176.80	502.7		5,691,434.86	2,219,109.42	182.6		14,727,668.95	5,931,184.70	611.1		2,740,076.18	1,086,545.35	125.0		7,867,698.81	Kansas
Kentucky	10,822,960.31	4,613,947.26	429.4		2,801,360.16	869,563.46	88.8		8,404,026.37	2,388,483.13	294.5						1,087,698.81	Kentucky
Louisiana	8,489,463.18	3,536,143.26	661.2		1,524,997.08	745,374.93	127.7		4,794,026.33	2,388,483.13	294.5		118,433.78	66,216.89	0.6		436,213.69	Louisiana
Maine	8,911,056.78	3,259,935.38	230.7		376,334.08	469,161.61	39.0		1,031,111.08	490,979.89	35.3		166,738.11	55,660.00	4.2		1,582.84	Maine
Maryland	24,037,561.24	9,865,843.07	243.2		3,558,411.02	1,719,205.49	16.4		2,801,989.31	1,199,249.89	86.3		166,738.11	55,660.00	4.2		1,582.84	Maryland
Massachusetts	10,191,202.02	4,105,727.22	232.8		318,961.44	111,675.42	5.2		6,457,832.90	2,063,941.50	105.7		614,513.78	213,801.89	12.6		1,431,233.97	Massachusetts
Michigan	13,434,135.07	6,080,612.23	484.5		5,902,734.87	428,447.25	44.5		15,538,028.85	7,543,209.56	533.3		163,170.00	81,905.00	0.4		1,768,971.96	Michigan
Minnesota	24,037,561.24	9,865,843.07	243.2		6,378,124.65	2,812,796.97	429.2		6,304,972.38	2,556,600.00	665.1		679,082.56	46,300.00	0.7		6,876.96	Minnesota
Mississippi	7,889,133.89	3,629,941.29	655.0		1,466,854.97	594,789.48	99.0		8,892,005.48	4,269,227.97	613.6		441,531.06	220,766.02	37.4		497,548.64	Mississippi
Missouri	11,352,027.70	5,845,859.18	803.5		2,446,556.80	1,214,687.84	134.5		23,887,359.86	10,043,178.40	855.4		3,897,800.67	1,001,725.65	147.3		3,681,885.53	Missouri
Montana	8,867,279.16	4,384,335.12	791.4		1,286,667.67	804,270.67	110.9		2,038,184.14	1,505,217.92	180.6		1,038,200.22	850,707.66	117.2		1,881,885.63	Montana
Nebraska	7,876,337.16	3,714,691.59	1,440.4		422,885.75	198,859.17	27.6		8,295,840.26	4,061,116.80	986.5		476,498.05	238,248.01	66.6		3,239,030.43	Nebraska
Nevada	3,460,245.82	1,553,624.98	225.6		1,169,995.85	987,072.91	97.5		4,623,107.75	3,867,914.62	395.8						191,709.48	Nevada
New Hampshire	3,076,750.19	1,487,867.58	171.3		849,260.28	331,365.29	29.9		992,047.86	466,732.70	30.9		40,305.73	19,027.23	1.6		89,871.20	New Hampshire
New Jersey	7,623,795.12	2,681,531.49	146.7		1,907,419.04	469,910.00	28.7		8,714,399.91	2,622,731.84	61.1		261,862.31	85,965.00	5.7		759,109.27	New Jersey
New Mexico	5,306,286.45	2,758,849.60	714.3		4,779,309.93	974,985.81	125.6		6,066,726.70	3,953,689.25	626.2		250,863.39	154,354.77	16.7		5,677,927.00	New Mexico
New York	18,862,745.49	8,257,844.44	572.7		2,003,973.68	821,459.81	56.5		30,460,474.84	11,411,244.38	677.4		5,768,436.00	1,829,465.00	105.6		4,868,114.37	New York
North Carolina	12,567,735.97	5,076,757.66	984.7		5,397,099.84	1,931,114.21	150.6		7,195,885.06	2,907,428.14	200.8		1,142,317.45	522,133.02	34.3		1,256,757.97	North Carolina
North Dakota	9,088,973.11	4,418,905.42	1,587.9		1,416,956.81	691,180.31	287.9		2,836,909.40	1,424,053.85	384.8		362,221.75	181,110.63	33.4		1,648,815.69	North Dakota
Ohio	33,122,751.43	11,879,917.89	962.5		5,303,843.08	2,180,246.30	143.7		11,038,959.07	3,976,562.41	314.4		1,784,535.68	704,250.15	58.6		1,470,183.15	Ohio
Oklahoma	12,986,865.25	5,888,852.03	497.3		4,518,160.07	2,183,240.84	190.2		7,391,946.19	3,360,295.50	323.8		974,215.64	413,900.04	83.6		700,384.58	Oklahoma
Oregon	12,082,873.17	5,819,033.79	655.6		1,209,095.39	707,463.39	95.4		3,235,246.67	1,906,755.73	147.4		150,205.00	56,340.61	3.1		1,616,892.48	Oregon
Pennsylvania	36,825,248.98	14,114,694.79	729.7		2,368,874.24	910,692.90	49.7		82,071,675.04	6,018,252.80	370.8		2,668,397.38	777,200.50	51.5		2,780,770.81	Pennsylvania
Rhode Island	1,774,397.25	779,297.95	46.0		744,122.80	309,710.13	16.7		1,295,720.34	371,918.64	17.8		260,738.95	64,170.33	21.7		472,184.07	Rhode Island
South Carolina	9,016,476.73	4,124,045.22	924.4		1,638,997.63	752,239.05	160.5		6,059,138.86	2,312,102.40	480.7		220,684.20	4,100.00	45.5		434,989.00	South Carolina
South Dakota	8,674,897.86	4,244,636.27	989.8		2,478,987.36	1,296,070.77	368.2		6,597,432.12	3,497,891.43	865.6		5,007,316.46	1,411,681.70	83.6		47,047.82	South Dakota
Tennessee	6,805,933.35	3,313,936.07	259.6		4,992,548.45	2,466,280.77	170.5		12,111,693.38	5,497,891.43	432.9		530,314.24	265,156.61	36.9		481,400.12	Tennessee
Texas	42,341,698.56	16,190,624.91	3,122.8		6,230,119.86	2,485,625.11	399.6		24,133,852.77	9,770,969.39	1,440.3		8,087,679.89	2,264,879.36	359.8		1,018,094.25	Texas
Utah	3,304,423.75	1,895,805.92	122.0		1,379,315.41	875,315.41	130.5		4,128,493.86	1,606,300.00	140.3		215,416.46	141,681.70	83.6		494,817.82	Utah
Vermont	1,822,114.18	942,759.12	74.4		811,354.15	104,186.61	7.5		2,053,399.68	980,721.61	51.6		28,427.26	14,213.68	0.1		482,076.14	Vermont
Virginia	10,035,201.48	4,801,782.43	562.5		1,350,803.33	634,648.93	56.5		5,045,806.93	4,830,374.42	356.4		624,765.32	249,304.08	24.2		78,630.63	Virginia
Washington	11,354,515.67	5,230,895.45	467.0		1,133,699.22	492,402.07	61.8		3,300,999.79	1,606,300.00	130.6		403,543.50	187,600.00	13.3		349,480.48	Washington
West Virginia	5,489,747.66	2,365,041.53	255.5		1,655,196.35	716,620.21	55.6		4,473,244.28	1,946,014.09	143.2		77,099.65	27,448.00	0.4		700,008.17	West Virginia
Wisconsin	18,753,303.15	7,441,033.67	1,325.3		1,836,535.77	884,535.77	75.3		3,808,509.79	1,633,415.16	155.5		53,417.25	26,700.00	3.9		3,532,756.48	Wisconsin
Wyoming	6,127,625.61	3,078,080.70	687.6		1,716,482.72	1,056,194.97	182.0		3,698,057.10	2,297,125.40	220.8		86,307.48	55,730.00	6.4		800,135.93	Wyoming
Hawaii																	\$46,635.00	Hawaii
TOTALS	549,569,391.27	237,802,399.62	32,412.9		101,601,856.04	47,415,840.83	5,584.6		391,153,760.23	173,503,011.86	17,609.1		35,282,346.69	13,744,109.45	1,185.8		\$4,838,938.02	TOTALS

* Includes projects reported completed (final vouchers and year paid) totaling: Estimated cost \$ 121,406,643.87 Federal aid \$ 53,678,414.10 Miles 4,890.4

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

DEPARTMENT BULLETINS

- No. 105. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
- *136. Highway Bonds. 20c.
- 220. Road Models.
- 257. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
- *314. Methods for the Examination of Bituminous Road Materials. 10c.
- *347. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
- *370. The Results of Physical Tests of Road-Building Rock. 15c.
- 386. Public Road Mileage and Revenues in the Middle Atlantic States, 1914.
- 387. Public Road Mileage and Revenues in the Southern States, 1914.
- 388. Public Road Mileage and Revenues in the New England States, 1914.
- 390. Public Road Mileage in the United States, 1914. A Summary.
- *393. Economic Surveys of County Highway Improvement. 35c.
- 407. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
- *463. Earth, Sand-Clay, and Gravel Roads. 15c.
- *532. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
- *537. The Results of Physical Tests of Road-Building Rock in 1916, Including all Compression Tests. 5c.
- *555. Standard Forms for Specifications, Tests, Reports, and Methods of Sampling for Road Materials. 10c.
- *583. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.
- *586. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1916. 10c.
- *660. Highway Cost Keeping. 10c.
- 670. The Results of Physical Tests of Road-Building Rock in 1916 and 1917.
- *691. Typical Specifications for Bituminous Road Materials. 10c.
- *704. Typical Specifications for Nonbituminous Road Materials. 5c.
- *724. Drainage Methods and Foundations for County Roads. 20c.
- *1077. Portland Cement Concrete Roads. 15c.
- *1132. The Results of Physical Tests of Road-Building Rock from 1916 to 1921, Inclusive. 10c.

* Department supply exhausted.

- No. 1216. Tentative Standard Methods of Sampling and Testing Highway Materials, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.
- 1259. Standard Specifications for Steel Highway Bridges adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.

DEPARTMENT CIRCULAR

- No. 94. TNT as a Blasting Explosive.

FARMERS' BULLETINS

- No. *338. Macadam Roads. 5c.
- *505. Benefits of Improved Roads. 5c.

SEPARATE REPRINTS FROM THE YEARBOOK

- No. *727. Design of Public Roads. 5c.
- *739. Federal Aid to Highways, 1917. 5c.
- *849. Roads. 5c.

OFFICE OF PUBLIC ROADS BULLETIN

- No. *45. Data for Use in Designing Culverts and Short-span Bridges. (1913.) 15c.

OFFICE OF THE SECRETARY CIRCULARS

- No. 49. Motor Vehicle Registrations and Revenues, 1914.
- 59. Automobile Registrations, Licenses, and Revenues in the United States, 1915.
- 63. State Highway Mileage and Expenditures to January 1, 1916.
- *72. Width of Wagon Tires Recommended for Loads of Varying Magnitude on Earth and Gravel Roads. 5c.
- 73. Automobile Registrations, Licenses, and Revenues in the United States, 1916.
- 74. State Highway Mileage and Expenditures for the Calendar Year 1916.
- 161. Rules and Regulations of the Secretary of Agriculture for Carrying out the Federal Highway Act and Amendments Thereto.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

- Vol. 5, No. 17, D-2. Effect of Controllable Variables Upon the Penetration Test for Asphalts and Asphalt Cements.
- Vol. 5, No. 20, D-4. Apparatus for Measuring the Wear of Concrete Roads.
- Vol. 5, No. 24, D-6. A New Penetration Needle for Use in Testing Bituminous Materials.
- Vol. 10, No. 7, D-13. Toughness of Bituminous Aggregates.
- Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

APPORTIONMENT OF FEDERAL AID FUNDS AUTHORIZED TO BE APPROPRIATED BY H. R. 4971 FOR THE FISCAL YEAR 1926

STATES	AMOUNT	STATES	AMOUNT
Alabama	\$1,541,870	Nevada	\$948,076
Arizona	1,056,171	New Hampshire	365,625
Arkansas	1,264,164	New Jersey	935,082
California	2,472,636	New Mexico	1,185,166
Colorado	1,373,237	New York	3,657,096
Connecticut	474,801	North Carolina	1,699,168
Delaware	365,625	North Dakota	1,180,699
Florida	892,878	Ohio	2,789,588
Georgia	1,983,089	Oklahoma	1,755,105
Idaho	936,927	Oregon	1,179,668
Illinois	3,191,479	Pennsylvania	3,360,123
Indiana	1,938,693	Rhode Island	365,625
Iowa	2,070,396	South Carolina	1,052,549
Kansas	2,074,360	South Dakota	1,215,020
Kentucky	1,411,607	Tennessee	1,622,985
Louisiana	997,262	Texas	4,415,715
Maine	685,140	Utah	846,467
Maryland	635,783	Vermont	365,625
Massachusetts	1,090,118	Virginia	1,449,713
Michigan	2,225,227	Washington	1,118,987
Minnesota	2,124,151	West Virginia	797,295
Mississippi	1,291,960	Wisconsin	1,873,308
Missouri	2,417,727	Wyoming	934,947
Montana	1,548,473	Hawaii	365,625
Nebraska	1,581,969	Total	73,125,000

